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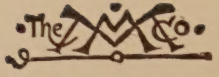
TEXT-BOOK OF ANATOMY AND PHYSIOLOGY



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TEXT-BOOK

OF

ANATOMY AND PHYSIOLOGY

BY

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AND

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PREFACE

Thirty three years of service as a text-book. That is the record of Kimber-Gray's Anatomy and Physiology, a record of steady growth based on meeting the needs of a growing profession, and of a host of other students in schools and colleges. That it has been able to meet these needs is due to the interest and help of many teachers and co-workers whose constructive criticism has been the working guide for each revision. It is a privilege to acknowledge this co-operation and express warm appreciation of it. But this is not all. Students in large numbers have checked the portions they have found especially difficult and in each revision a special effort has been made to simplify such portions. It is however extremely difficult to present what is essentially complex in simple form. It is equally difficult to be brief and at the same time to avoid being dogmatic about processes which experimental research workers are revealing as *more*, rather than *less* intricate. Because of this it is necessary to present guarded and qualified statements of what may be, rather than clean-cut statements of what is. Students are apt to find such statements unsatisfactory, but there is always the hope that they may stimulate an open-minded, questioning attitude that is highly desirable. One reason for many of the difficulties encountered, is that physical and organic chemistry are interwoven in a most intimate way with physiology, and their study should precede that of physiology. Where this is done it is comparable to furnishing students with a *key* that unlocks the door of many seeming mysteries.

Some of the illustrations have been redrawn and new ones have been added. The anatomical names in even the most recent books on anatomy vary, consequently preference has been given to such new names as have been generally adopted, and such old ones as seem too firmly entrenched in our language to be dislodged. In almost every instance, both terms are given. An attempt has been made to simplify the chapters on the Nervous System, and the psychology has been omitted, because so many text-books treating of this subject are now available.

The sequence and arrangement of the chapters have met with such approval that they have not been changed. However, it may

often be desirable to vary the sequence, and any particular plan is to be looked upon as suggestive, and only one of many possible good ones.

The glossary has been reduced as most of the words are fully explained in the text, and the use of the index makes it easy to locate the explanations. In compiling such summaries as are found at the end of the chapters, one is always faced with the question whether the classification is to be of the chapter contents or whether it is to be of subject matter without reference to the chapter. In this text the summaries are to be looked upon as one way of classifying the chapter contents. It is gratifying to know that the summaries are helpful to students in organizing the material presented in classes, and serve as an endless source of questions which can be easily varied and hence are less apt to become monotonous.

The Bibliography found on page 526 represents a minimum of necessary reference books rather than a complete list. At least one or two copies of each type of book, *i.e.*, anatomy, physiology, chemistry, etc., should be available to be used, not only by such students as are capable of advanced work, but rather by all students, as it is obvious that the descriptive matter in a text of 525 pages cannot be as detailed as in one of several times that number. Moreover the specialist in any one field cannot follow critically the researches of all his colleagues in other fields. Consequently it is inevitable that in writing texts specialists emphasize and usually clarify their own special fields of work. Witness the books that are specially good on one or another phase of physiology. Because of this, not one but many books are needed, and a reference library ought to be a *growing* thing. It is essential that copies of new editions should be added constantly, for in no field of knowledge are greater strides being made than in human physiology.

I am indebted to many co-workers, especially Caroline E. Stackpole, A.M., Instructor in Biology, Teachers College, for reading and criticising my manuscript; Elsa Schmidt, A.M., R.N., for assistance in the preparation of the manuscript; Dr. R. J. E. Scott for reading the proof and making the index; and the representatives of The Macmillan Company, Mr. J. Norris Myers and his staff, for unfailing courtesy and helpfulness. I am also indebted to the authors I have consulted, and the various publishers who have granted me permission to use illustrations from their books.

C. E. G.

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TEXT-BOOK OF ANATOMY AND PHYSIOLOGY

CHAPTER I

DEFINITIONS—CAVITIES AND REGIONS OF THE HUMAN BODY

The study of anatomy and physiology is simplified if certain terms which occur quite frequently are understood.

Science is concerned with facts which have been systematized and formulated.

Biology is the science of living things. Much of our knowledge of the chemical nature and the life processes of man has been obtained from the study of lower animals and plants. These processes are much more similar than the differences in their outward appearance would suggest. Among the biological sciences are embryology, histology, anatomy, physiology, psychology, sociology, hygiene, etc.

Embryology is the science of the early development and growth of living things.

Histology is the science of minute or microscopic structure. It is often defined as *microscopic anatomy*. Histology makes clear the structure of cells, the arrangement of cells in tissues, and the combination of the tissues to form organs. Normal histology is the science of healthy tissues and cells. Pathology is the science of diseased tissues and cells.

Anatomy is the science of organic structure. Human anatomy refers to the gross structure of the human body. Comparative anatomy compares the structure of the human body with that of the lower animals. The study of anatomy is usually carried out on the dead bodies of animals and plants since it is not concerned with their activity.

Physiology is the science of function. It shows us what the organs do in relation to each other, hence it is concerned with the complete animal or plant, showing the functional relationships of organ to organ in the harmonious behavior of the organism as a unit.

Psychology is the science of behavior.

Sociology is the science of group living.

Hygiene is the science of healthful living.

These sciences may be grouped under the general science of *Zoology*—for instance, animal anatomy, animal physiology, etc.

They may be grouped under the general science *Botany*—for instance, plant anatomy, plant physiology, etc. They may be *Comparative*—for instance, comparative anatomy, comparative physiology, etc. They may be *Applied*—for instance, applied anatomy, applied physiology, etc. The laws of physiology if

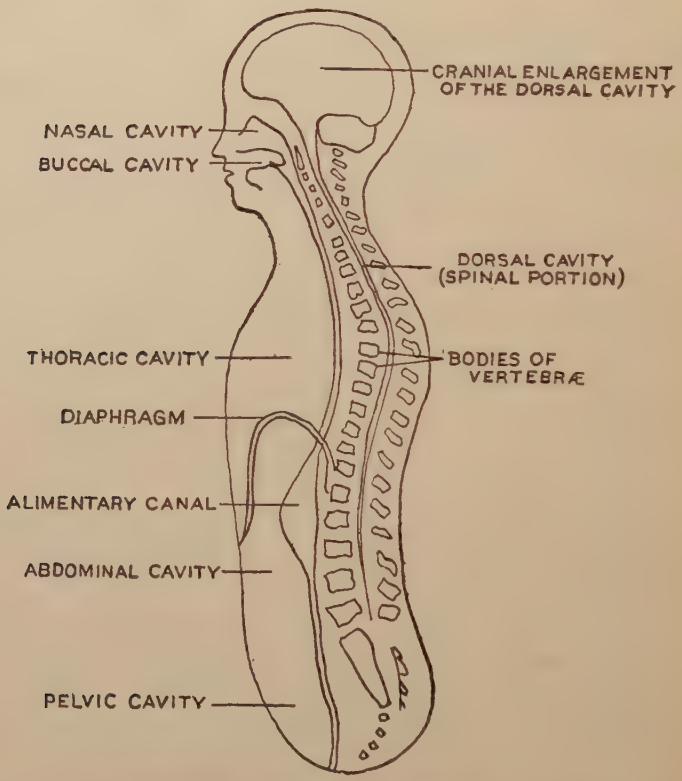


FIG. 1.—DIAGRAMMATIC LONGITUDINAL SECTION OF THE TRUNK AND HEAD. The alimentary canal is represented running through the whole length of the ventral cavity.

applied to man give us the science of hygiene, if applied to animals and plants give us the science of animal or plant conservation.

The vertebrates.—The distinguishing anatomical character of all vertebrate[1] animals is the presence in the trunk of a

[1] Included in the vertebrates are groups of fishes, amphibians, reptiles, birds, and mammals. Mammals are animals that nourish their young with milk secreted by mammary glands. They also have more or less hair on the skin, *e.g.*, whale, beaver, man, etc.

vertebral column which separates a dorsal and a ventral cavity.[2]

The dorsal cavity.—The dorsal cavity is continued through the neck into the head and there widens out to form the cranial cavity. It is a complete bony cavity formed by the bones of the skull (cranial)[3] and the bones of the spine (vertebrae).[4]

(1) *The cranial cavity* contains the brain.

(2) *The spinal cavity* is continuous with the cranial cavity and contains the spinal cord. The spinal cord is continuous with the brain.

The ventral cavity.—The ventral cavity is not a complete bony cavity, part of the walls are formed by muscular and other tissues. In mammals it is subdivided by the diaphragm into two main cavities, the thoracic and abdominal.

1. *The thoracic cavity*, or chest, contains the trachea or windpipe, the lungs, esophagus or gullet, heart, and the great vessels springing from, and entering into, the heart.

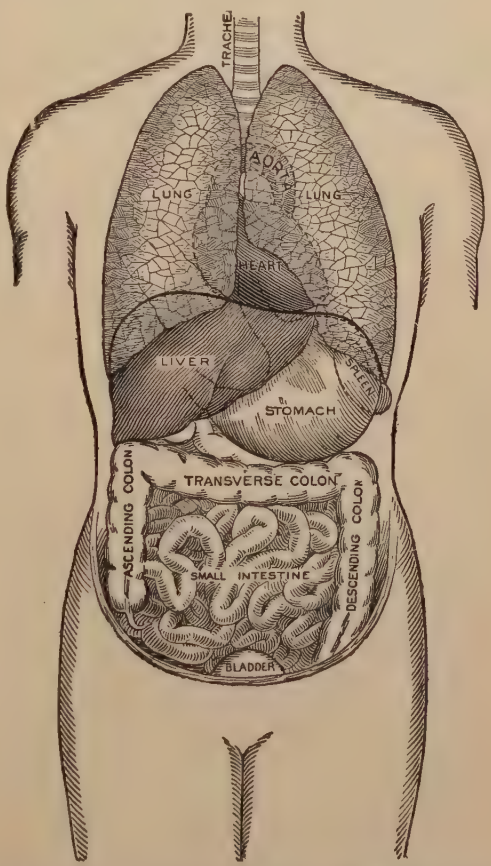


FIG. 2.—POSITION OF THE THORACIC AND ABDOMINAL ORGANS (FRONT VIEW). (Morrow.)

Diaphragm. — The diaphragm is a dome-shaped musculo-membranous partition between the thoracic and abdominal cavities.

[2] It will be noticed we are using the term cavity in different senses. For instance, in one sense in reference to the internal cavities, the dorsal, thoracic and abdominal; and in more general sense to the more open cavities, such as the orbital, nasal and buccal cavities.

[3] See page 43. [4] See page 51.

2. *The abdominal or peritoneal cavity* contains the stomach, liver, gall-bladder, pancreas, spleen, small and large intestines.

The *pelvic cavity* is that portion of the abdominal cavity lying below an imaginary line drawn across the prominent crests of the hip bones. It is more completely bounded by bony walls than the rest of the abdominal cavity. It is divided by a narrow bony ring—the pelvic inlet—into the large, false pelvis above, and the small, true pelvis below. (See Fig. 53.) The small or true pelvis contains the bladder, rectum, and some of the generative organs.

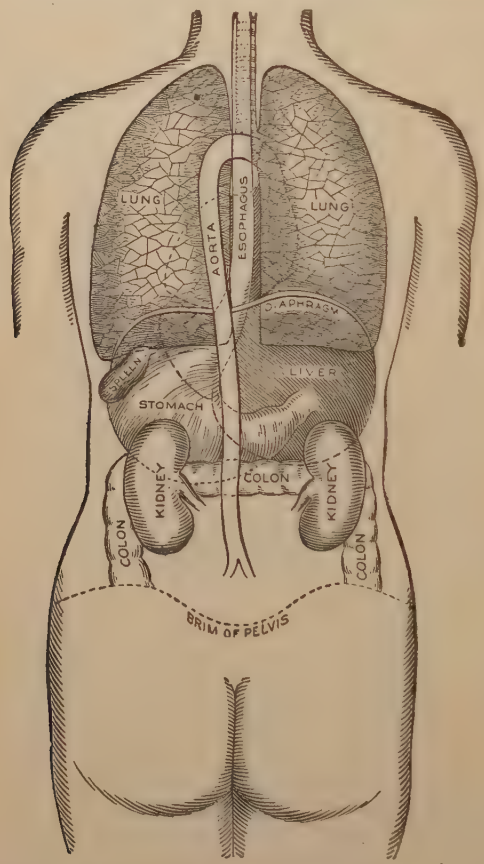


FIG. 3.—POSITION OF THE THORACIC AND ABDOMINAL ORGANS (REAR VIEW.) (MORROW.)

A survey of the skeleton shows three small cavities in the skull, in addition to the cranial, which for the sake of simplicity in study are included here.

1. *The orbital cavity* contains the eye, the optic nerve, the muscles of the eyeball, and the lacrimal apparatus.

2. *The nasal cavity* is filled in with the structures forming the nose.

3. *Buccal cavity.*—The buccal cavity or mouth contains the tongue, teeth, and salivary glands.

It is helpful to consider the human body as comparable to a community which is divided into localities or districts, these districts being given distinctive names. Furthermore we may think of this community as made up of industrial units, each one carrying on special work, but dependent upon and

coöperating with all the other units, the arrangement and location of each being determined by the efficiency of the whole. In order to understand any such coöperative community it would be necessary to study (1) the different districts, (2) the industrial units and their subdivisions, (3) the structure, and (4) the functions of each unit.

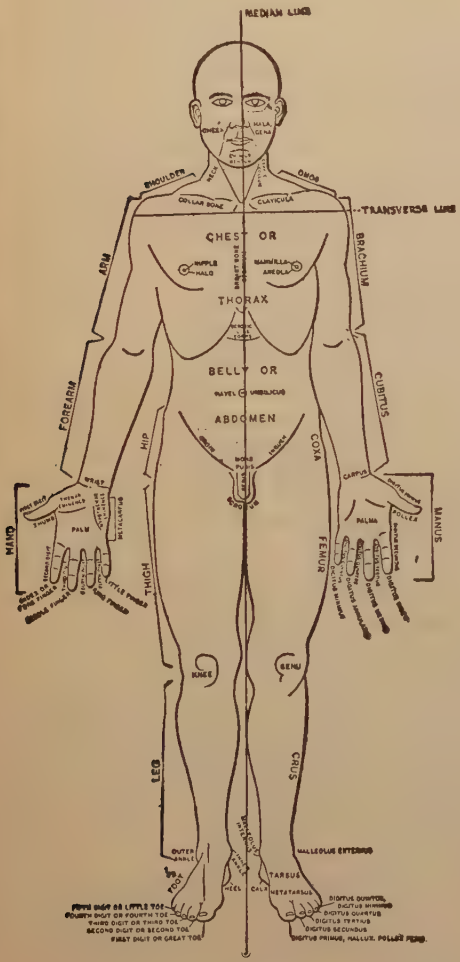


FIG. 4.—FRONT VIEW OF A MAN IN THE ANATOMICAL POSITION. On the right lateral half the parts are labelled in English, on the left in Latin. The right upper limb is drawn away from the trunk in order to show the arm more fully than is possible when it hangs perpendicularly. (Gerrish.)

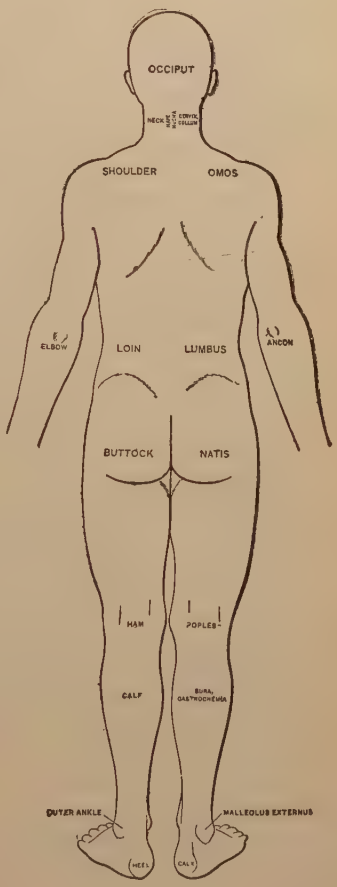


FIG. 5.—BACK VIEW OF A MAN. On the left lateral half the names of the parts are given in English, on the right in Latin. (Gerrish.)

Figs. 4 and 5 are worthy of careful study as the regions (districts) of the body are labeled.

Due to the fact that man walks erect and the majority of mammals go on all fours, confusion is apt to arise in the use of terms used to describe corresponding parts of man and other animals. To avoid this confusion anatomists have given these terms arbitrary significance.

The anatomical position.—In describing the body, anatomists always consider it as being in the erect position, with the face toward the observer, the arms hanging at the sides, and the palms of the hands turned forward.

Since the study of comparative anatomy has become more general most anatomists have agreed to call the head end of an animal or man, anterior; the opposite end, posterior; the side containing the backbone, dorsal; and the opposite side, ventral. Anterior is the same as superior, posterior is synonymous with inferior. The head end is also spoken of as superior and opposite end inferior. The terms cephalic and caudal are sometimes used as synonymous with superior and inferior. In line with all recent editions of anatomies, this use of the words will be adhered to.

The median or sagittal line.—This refers to an imaginary line drawn through the middle of the body, from the top of the head through the sagittal suture (see Fig. 60) to the floor at a middle line between the feet, dividing the body into right and left halves. The parts nearest this line are described as *mesial*, the parts farthest from this line are described as *lateral*.

Internal and external are reserved almost entirely for describing the walls of cavities or of hollow viscera.

Proximal is used to describe a position near the source of any part. *Distal* is used to describe a position distant, or farthest away from the source of any part. Thus we speak of the proximal end of the arm, and the distal end of a finger.

In anatomy the term *periphery* means the outside or surface of a body or an organ.

SUMMARY

Science is concerned with facts. Biology is the science of living things.

Biological Sciences (Embryology, Histology, Anatomy, Physiology, Psychology, Sociology, Hygiene, etc.)

These may be branches of

1. Zoology (if derived from a study of animals).
2. Botany (if derived from the study of plants).
3. Comparative Biology (if derived from a comparison of animals and plants).
4. Applied Biology (if the principles are applied to healthful living—for instance:
   (1) Hygiene of man.
   (2) Conservation of plants and animals).

HUMAN BODY

Dorsal Cavity

1. **Cranial cavity**—Brain.
2. **Spinal canal**—Spinal cord.

Ventral Cavity

1. **Thoracic cavity**
   - Esophagus—Trachea.
   - Lungs—Heart.
   - Blood-vessels.

The Diaphragm separates the thoracic and abdominal cavities.

2. **Abdominal cavity**
   - Stomach—Spleen—Pancreas.
   - Liver—Gall-bladder.
   - Large and small intestines.[5]
   - **Pelvic cavity** (Lower portion abdominal cavity)
     1. Large, false pelvis.
     2. Small, true pelvis.
     - Bladder — Rectum.
     - Some of the generative organs.

Facial Aspect of Skull

1. **Orbital cavity**
   - Eye. Optic nerve.
   - Muscles of the eyeball.
   - Lacrimal apparatus.
2. **Nasal cavity** — Structures forming the nose.
3. **Buccal cavity**
   - Tongue. Teeth.
   - Salivary glands.

[5] The kidneys are behind the peritoneum, a serous membrane which lines the abdominal cavity, hence, though apparently in the body cavity, they are retro-peritoneal and are therefore not actually contained within the abdominal cavity.

CHAPTER II

SYSTEMS, ORGANS, TISSUES, CELLS

If we press our comparison of the human body to a coöperative community, we find that there is a division of labor in the body, and certain organs are associated with each other for the performance of special functions that promote the efficiency and welfare of the whole. An arrangement of organs closely allied to each other and concerned with the same function is called a *system* and is comparable to an industrial unit.

Nine systems are found in the human body. Their names, the organs of which they consist and the functions of each are briefly expressed as follows:—

Skeletal system.—This system consists of the bones of the body. The main function is support.

Muscular system.—This system consists of the voluntary and the involuntary muscles. The main function is to contract and to cause motion.

Nervous system.—This system consists of the central nervous system and the autonomic[1] nervous system. The main function is to control and insure coördination in the working of all the systems in the body. It contains the center for all the sensations, intelligence and thought that we recognize as the highest functions of life.

Vascular or Circulatory system.—This system consists of the heart, blood-vessels and blood; lymphatics and lymph. The main function is to distribute body fluids to all the cells.

System of Internal secretions.—This system[2] consists of the ductless glands, *e.g.*, thyroid, adrenals, etc., and portions of the glands with ducts, *e.g.*, the islands of Langerhans in the pancreas, portions of the ovaries and testes, etc. Our rapidly accumulating knowledge in this field seems to indicate that every cell is a ductless gland. The function of this system is to contribute

[1] For subdivisions of the nervous system see page 117.

[2] This might not be counted as a separate system, but of being composed of part of the other systems. Such a classification would show eight biological systems.

substances to the blood stream which affect the activity of the body cells.

Respiratory system.—This system consists of the nose, larynx, trachea, bronchi and lungs. The function is to provide oxygen and get rid of excess carbon dioxide.

Alimentary system.—This system consists of the digestive canal and the accessory glands, *i.e.* the salivary glands, the pancreas and the liver. The function is to receive, digest and absorb food.

Excretory system.—This system consists of the urinary organs, *i.e.* the kidneys, ureters, bladder and urethra, and in a limited sense the respiratory and alimentary systems and the skin.[3] The function is to eliminate the waste products that result from cell activity.

Reproductive system.—This system consists of the testes and their ducts in the male; the ovaries, uterus, tubes and vagina in the female. The function is to insure the continuance of the race by the production of other beings.

It is important to remember that these different systems are closely interrelated and dependent on each other. While each forms a complete unit, specially adapted for the performance of some function, yet that function cannot be properly performed without the assistance and coöperation of other systems. The most perfect skeleton is not capable of support unless assisted by the muscular and nervous systems. Any interference with the circulatory system also affects the work of the excretory system, etc.

Organs.—Further analysis of our industrial units or systems shows them to be made up of smaller units or organs, with a corresponding division of labor, and special adaptation of the organ to its particular share of the work of the system. For example, the excretory system consists of the following organs:—

Two kidneys, which form the urine by eliminating waste materials from the blood.

Two ureters, ducts which convey the urine from the kidneys to the bladder.

One bladder, a reservoir for the reception of urine.

One urethra, a tube through which the urine passes from the bladder and is finally voided.

The interdependence of these organs is obvious, and differences

[3] For the skin and its work in excretion, *e.g.*, the elimination of heat see Chapter XXI.

in function suggest differences in structure. We find this to be the case, and our definition of an *organ* is that it is a physiological unit composed of two or more different *tissues* associated in performing some special function, and specially adapted to the performance of that function.

Tissues.—Microscopic study of tissues reveals the fact that tissues are made up of smaller units or cells, and these cells are the ultimate physiological and structural units of the body.

Each tissue is a collection of similar cells arranged together and having some specialized function to perform. The cells are held together by *intercellular* substance secreted by the cells, or by anastomosing processes of the cells. This intercellular substance varies in amount, in composition, and in many cases determines the nature of the tissue, for example, muscle and bone.

Cells.—Due to the fact that cells are physiological and structural units of the body, it is necessary to understand their activities and structure. Low down in the scale of life we find animals so simple that they are described as consisting of just one cell. These unicellular animals are alive because they are capable of carrying on the biological functions which are essential to life. Briefly these biological functions are irritability to environment, breathing, digesting, excreting, distributing and collecting, moving, and reproducing. The ameba, a typical one-cell animal, can be observed under the microscope carrying on these functions. The life of each individual cell in the body is dependent on its ability to carry on these functions.

As we ascend in the scale of life, we find animals that consist of a greater number of cells. The human animal may properly be described as a multicellular animal consisting of an enormous aggregate of cells. In multicellular animals individual cells are often remote from air and food, and from the excreting organs, and must rely upon the circulating fluids to carry air and food to them, and waste matters from them. The systems of the body represent an adaptation and specialization of groups of cells to carry on the biological activities for the body as a whole. A comparison of the biological activities of a unicellular animal with the biological activities of the cells of multicellular animals,[4] and the functions performed by the systems of the body, show them to be essentially the same.

[4] See page 12.

Structure of the cell.—A cell[5] is a minute portion of living substance enclosed in a cell membrane which is thin and delicate. The cell contains a nucleus, an oval or spherical body surrounded by its membrane. This in turn often contains one or more smaller bodies or nucleoli.

Protoplasm is a general term for living substance. The protoplasm of the cell body exclusive of the nucleus is called *cytoplasm*

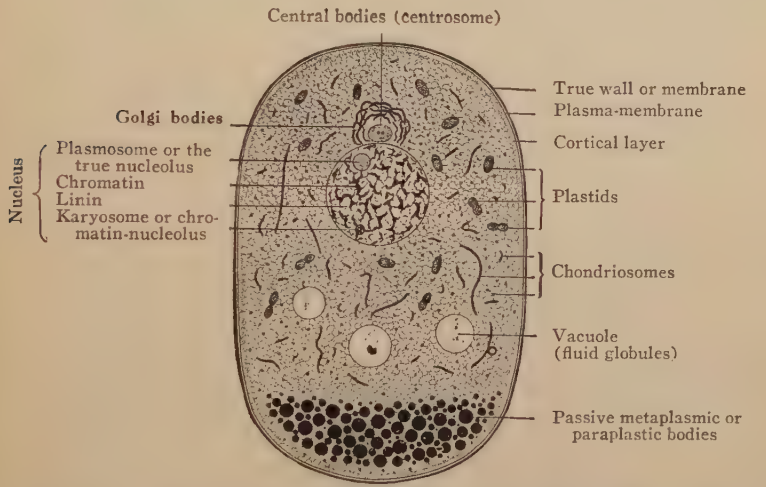


FIG. 6—Diagram of a generalized cell. Modified from Wilson "The Cell in Development and Heredity," 3rd edition. The chromatin is more technically called *basichromatin* since it stains with basic dyes; the linin is likewise called *oxychromatin* since it reacts to acid dyes. *The Golgi bodies** are usually found near the nucleus. Though imperfectly known they are thought to function in secretion. *Plastids* are areas of special chemical activity leading to the production of special substances, *i.e.* starch grains in plant cells. *Chondriosomes* are thought to function in the production of germ cells.

It varies in extent and in appearance in different cells, being sometimes homogeneous, sometimes alveolar, and sometimes granular in structure.

That portion of the protoplasm inside the nuclear membrane is called the *nucleus*. It consists of a fine network of material called *linin*, and on this are strung, so to speak, granules of a

* These bodies are also called the Golgi apparatus after Golgi who developed the method of staining with silver nitrate.

[5] The word cell is from the Latin *cella*—a cavity—and was first used by botanists to describe plant cells, like those of cork and elder pith, which have cavities in their substance. It is now known that most animal cells, and many plant cells, do not have cavities, so that the name is not especially appropriate, but it is too firmly fixed in our language to be abandoned.

material called chromatin. Beside these granules of chromatin other masses are sometimes found which stain in a different manner and are called *nucleoli*. By studying the behavior of cells or parts of cells deprived of a nucleus and comparing this behavior with that of similar cells containing a nucleus, it has been demonstrated that the nucleus is essential for (1) the chemical changes on which the nutrition and functioning of the cells depend, (2) it instigates the process by which cells multiply, and (3) it is thought that the chromatin of the nucleus constitutes the material that transmits characteristics from parents to children. In a cell which is about to divide this chromatin breaks up into segments called *chromosomes*. The number of chromosomes is always constant for the same species, but varies for different species.

The term *central bodies* (centrosomes) is applied to structures which are usually double, and which are associated with many cell activities, particularly cell division. During mitotic division and sometimes during the resting stage the central body is surrounded by fibrillæ which radiate like the rays of the conventional sun.

In the meshwork of protoplasm are often suspended various passive bodies such as food granules, pigment bodies, drops of oil, etc. These may represent reserve food material, or waste matters, and are nonliving substances collectively designated as *metaplastic*, or *paraplastic* substances.

Life activities in cells.—In order to live each cell must be capable of carrying on the activities necessary to life. These are (1) *Support.*—Each cell is afforded support by the cohesiveness of its own structure; by the cell wall if one exists; if not, then the outer circumference of the protoplasm approximates the function of a membranous support.

(2) *Respiration.*—Each cell coming in contact with oxygen absorbs it. Whenever this absorption takes place a certain amount of the cell contents is burned or oxidized, and as a result of this oxidation heat and other kinds of energy are produced, and carbon dioxide, which is a waste product, is formed. Thus it will be be seen that the real purpose of respiration is to furnish oxygen to each individual cell, and to take from the cell the excess carbon dioxide which it does not need (internal respiration, see page 319).

(3) *Metabolism.*—Each cell is able to take to itself, and eventually convert into its own substance, certain materials (foods) that are nonliving; in this way the protoplasm may increase in

* Metabolism, circulation and excretion are dependent upon the processes of *osmosis* and *dialysis*, a description of which will be found on pages 268 and 397.

amount, or, in other words, the cell may grow. The amount of protoplasm is not permanently increased, because only enough protoplasm is added by the process of assimilation to replace that incidentally oxidized. Chemical changes which involve the building up of living material within the cell have received the general name of *anabolic* changes, or *anabolism;* on the other hand, those which involve the breaking down of such material into other and simpler products are known as *catabolic* changes, or *catabolism*,[6] while the sum of all the anabolic and catabolic changes which are proceeding within the cell is spoken of as the *metabolism* of the cell. These chemical changes are always more

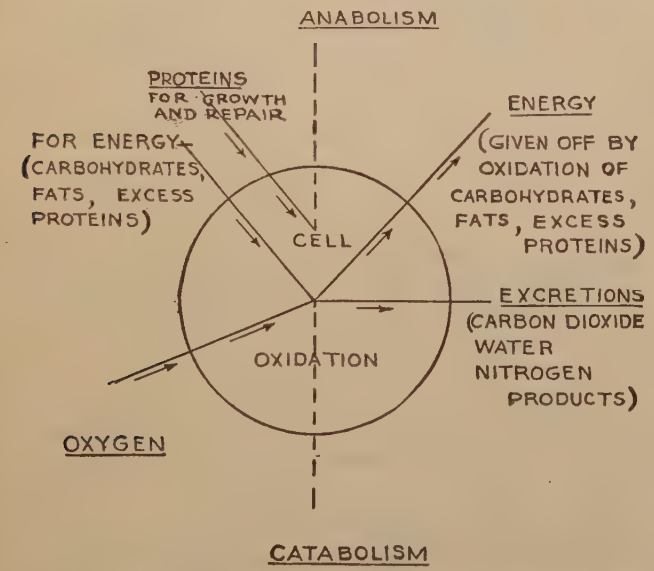


FIG. 7.—DIAGRAM SHOWING PROCESS OF METABOLISM IN A CELL.

marked as the activity of the cell is promoted by warmth, electrical or other stimulation, the action of certain drugs, etc.

(4) *Motion.*—This is exhibited in two different forms:—

(*a*) *Ameboid movement*[7] consists in the pushing outward by the cell of processes, called pseudopodia. These may be retracted or the contents of the cell may flow into them. In this way the cell may change both its shape and position. By a repetition of this process the cell may move slowly away from its original situation, so that an actual locomotion takes place, *e.g.*, white blood cells.

[6] This is also spelled katabolism.

[7] This term is derived from the ameba, a single-celled organism.

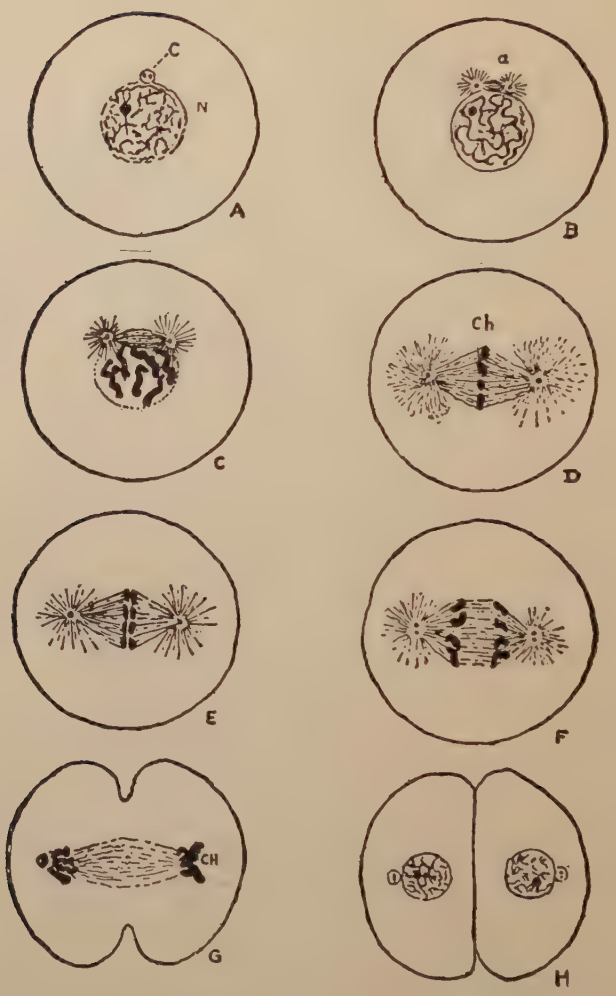


Fig. 8.—Diagrams to Show the Sequence of Events in Mitosis. This cell is presumed to have eight chromosomes. In C, six are shown, and in subsequent figures only four. The others are presumed to be on the other side of the spindle in another plane, and hence invisible. *A*, resting cell with nucleus (*n*) and centrosome (*c*). *B*, preparing to divide, two asters (*a*) near nucleus, each with a centrosome, chromatin being massed into chromosomes. *C*, centrosomes separating forming a spindle between them, nuclear membrane disappearing, chromosomes formed. *D*, chromosomes (*ch*) lying in the equator of the spindle. *E*, chromosomes divided lengthwise into halves. *F*, chromosomes separating and moving toward the centrosomes. *G*, chromosomes forming the two nuclei, and cell body beginning to divide. *H*, division complete, two-cell stage; each cell has the same structure as the one-cell in *A*. (Modified from Wilson.)

(*b*) *Ciliary movement* is the whipping motion possessed by little hair-like processes called cilia, which project from the surface of some epithelial cells.

(5) *Circulation.*—This consists in a "streaming" of the protoplasm, which occurs within the limits of the cell. By this means nutritive material or waste substances may be carried from one portion of the cell to another.

(6) *Excretion.*—Each cell is able to discharge and thus get rid of waste substances.

(7) *Irritability.*—Irritability is that property which enables a cell to respond to external stimuli. The response may take the form of an increase of some kind of activity, such as motion, growth, etc., or it may take the form of a decrease of these activities. If the response is an increased activity the protoplasm is said to be *excited*; if the response is a decreased activity the protoplasm is said to be *inhibited*. Cells vary in regard to their irritability, the most markedly irritable cells in higher animals being those of the nervous system.

(8) *Cell division.*—Like all living organisms, each cell grows, produces other cells, and dies, so that each cell has a life cycle comparable to, but much shorter than, the body itself. As the cells are constantly dying, the need for constant reproduction is apparent. This reproduction is accomplished in two ways, (*a*) simple direct division or amitosis and (*b*) indirect division or mitosis which is the almost universal method.

(*a*) In direct division the cell elongates, the nucleus and cytoplasm become constricted in the center and the cell divides and forms two cells which soon grow to the size of the original cell.

(*b*) In indirect division, or *mitosis*, the nucleus passes through a series of complicated changes. A careful study of Fig. 8 will give the student some idea of these changes.[8]

Differences in cells.—Cells differ in (1) size, (2) form, (3) chemical composition, and (4) function. (1) As an example of variation in size[9] a voluntary muscle cell is about an inch (25 mm.) long and $^1/_{500}$ of an inch (0.05 mm.) in diameter. The processes of a nerve cell may be 3 feet (1 meter) or more in length. A red blood cell has a diameter of $^1/_{3200}$ of an inch (about 0.008 mm.). (2) The simplest form of cell is spherical, but this is

[8] For a detailed description of mitosis the student is referred to "The Cell in Development and Heredity," by Wilson, 3rd edition.

[9] On page 525 will be found accurate ratios between the metric system and the system of lengths, weights, and measures used in the United States.

seldom realized except in unicellular plants and animals. In the human body the form of the cell is modified by the pressure of the surrounding structures, by active movement of the cell substance, and by growth and differentiation. (3) It is assumed that the marked difference in the appearance of cells is an expression of a chemical difference, which in turn is an evidence of difference in function. (4) Each cell in a multicellular animal has a dual function, (*a*) to carry on the activities on which its own life depends, and (*b*) by specialization in some one of them to assist in the work of the tissue of which it forms a part.

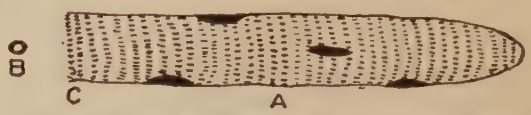


FIG. 9.—SIZES OF CELLS. *A*, voluntary muscle cell magnified in width 200 times and represented as cut off at *C*. At this magnification it would be about 200 inches long. *B*, red blood cell, also magnified about 200 times.

The constituents of protoplasm.—Chemical analysis of protoplasm has shown that it always contains the following elements:

Carbon	13.5	(C)	Form 97 per cent of total weight of body
Hydrogen	9.1	(H)	
Oxygen	72.0	(O)	
Nitrogen	2.5	(N)	
Sulphur		(S)	
Phosphorus		(P)	
Chlorin		(Cl)	
Sodium		(Na)	
Potassium		(K)	
Calcium		(Ca)	
Magnesium		(Mg)	
Iron		(Fe)	
Silicon		(Si)	
Fluorin		(F)	

In the human body free oxygen, hydrogen, and nitrogen have been found in the blood and intestines, but the bulk of these elements as well as all of the others exist in the form of complex compounds in the cells. These compounds are divided into two classes, *i.e.*, organic and inorganic. Those which contain carbon are organic, and those which do not are inorganic.

The *organic compounds* found in cells are carbohydrates, fats and proteins. They contain the same elements as the similarly named organic compounds of our food, *i.e.*, proteins of the human cells contain the same elements as the proteins of our food, etc. But it must not be understood that because of this they are exactly the same. Animal protein and human protein have dis-

tinctive characteristics, just as beef and mutton have distinctive characteristics. All three contain the same essential elements, but in different combinations, and the presence or absence of additional elements results in marked differences. The same holds true of carbohydrates and fats. The essential elements in proteins are carbon, hydrogen, oxygen, and nitrogen, probably also, sulphur and phosphorus; in carbohydrates and fats the essential elements are carbon, hydrogen, and oxygen. All organic compounds taken into the human body are split up into simple substances, *i.e.*, carbohydrates into simple sugars; fats into glycerin and fatty acids; proteins into amino-acids.[10] All of these simple substances are carried by the blood and lymph to the cells, and the cells are able to build them up into carbohydrates, fats, and proteins that are distinctly human. These may then be stored in the cells, or utilized for growth or the production of energy, as indicated in Fig. 7. A more complete discussion will be found in Chapters XVIII and XIX.

Chlorin, sodium, potassium, calcium, and magnesium play an essential part in all vital processes and must be present in foods, since they are constituents of protoplasm.

Iron probably exercises an important function in the processes of oxidation which are continually going on in all protoplasm. It is found in hemoglobin, a protein substance in the red blood cells; whose office is to carry oxygen from the lungs to the tissues.

In addition to the elements which probably enter into the structure of all protoplasm, the intercellular material of the human body contains small quantities of *fluorin* (constituent of bones and teeth), iodin (thyroid gland), and traces of manganese.

Water is one of the most essential needs of cells and constitutes over two-thirds of the body weight, hence the physiological need of water.[11]

SUMMARY

System.—An arrangement of organs, closely allied and concerned with the same function.

Nine systems are found in the human body:

Skeletal.	System of internal secretions.
Muscular.	Respiratory.
Nervous.	Alimentary.
Vascular, or circulatory.	Excretory.
	Reproductive.

Organs.—Two or more different tissues associated in performing some special function.

[10] For further discussion see page 366.
[11] For further discussion of water see page 362.

Tissue.—A collection of similar cells arranged together and having some special function to perform.

Cell.—The structural and physiological unit of the body.

Ameba.—An example of a unicellular animal which lives because it is able to carry on the biological activities of irritability, breathing, digesting, excreting, distributing and collecting, moving, and reproducing.

Comparable activities
- Biological activities of ameba.
- Functions of the nine systems in human body.
- Life activities of cells.

Cell
- Protoplasm
  - Cytoplasm
    - Central bodies.
    - Golgi bodies.
    - Plastids.
    - Chondriosomes.
    - Vacuoles.
  - Nucleus
    - Plasmosome or true nucleolus.
    - Chromatin (basichromatin).
    - Linin (oxychromatin).
    - Karyosome or chromatin nucleolus.
- Metaplastic or paraplastic bodies
  - Foods.
  - Wastes.
  - Other storage products.

Life activities in cells
1. Support
2. Respiration
   - Provides oxygen for oxidation.
   - Liberates heat.
   - Carbon dioxide removed.
3. Metabolism
   - Anabolism = building-up process.
   - Catabolism = breaking-down process.
4. Motion
   - (*a*) Ameboid movement.
   - (*b*) Ciliary movement.
5. Circulation—Streaming of the protoplasm, within the limits of the cell.
6. Excretion—Discharge of waste substances.
7. Irritability—Ability to respond to stimuli.
8. Cell division
   - (*a*) Simple, direct division.
   - (*b*) Indirect division or mitosis.

Differences in cells
- Size
  - Voluntary muscle cell may be an inch long.
  - Processes of nerve cells may be three feet or more.
  - Red blood cell 1/3200 inch in diameter (average).
- Form depends on
  - Pressure.
  - Movements of cell.
  - Growth and differentiation.
- Chemical composition—dependent on special work of cell.
- Function
  1. To carry on activities on which its own life depends.
  2. To assist in work of tissue of which it forms a part.

Bulk of elements found in body exist in form of compounds
- Organic—contain carbon
  - Carbohydrates.
  - Fats.
  - Proteins.
- Inorganic—contain no carbon.

Constituents of Protoplasm
- Carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, chlorin, sodium, potassium, calcium, magnesium, iron and silicon.
- Additional constituents in intercellular materials.
  - Fluorin. Iodin.
  - Traces of manganese.

Water—hydrogen and oxygen (H_2O)—is one of the most essential needs of cells. More than two-thirds of body weight is water.

CHAPTER III

TISSUE DIFFERENTIATION.—CONNECTIVE TISSUES

Leaving aside the questions involved in any discussion of the origin of life, biologists today believe that all cells are derived from preëxisting cells by a process of cell division as discussed in the previous chapter.

Reproduction.[1]—Reproduction of living organisms is accomplished in two ways:—

(1) Asexually; (2) sexually.

(1) In the asexual type one individual divides into two or more, as is seen in the budding of plants and animals, also in the unicellular organisms where one organism constricts itself into two, either directly or indirectly, by mitosis, or divides itself up into a number of spores.

(2) In the sexual type, the individuals make sex cells (gametes) which fuse to form the new individual. Fig. 10 shows the formation of gametes from the cells of the gonads (ovaries or testes). Each gamete has half the number of chromosomes found in the

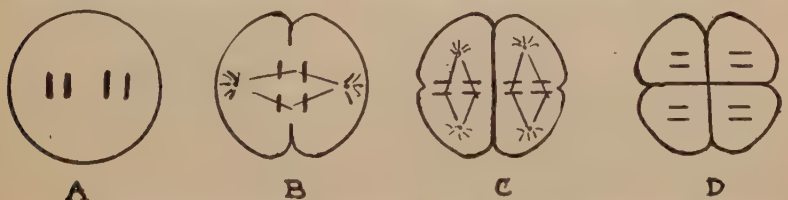


FIG. 10.—MATURATION OF GAMETE. *A*, a gamete-forming cell showing four chromosomes. *B*, *separation* of these four chromosomes into two groups. *C*, each of the cells formed in *B* is here shown with its chromosomes *divided longitudinally* in half. *D*, shows the mature gametes each with two chromosomes.

original gamete-forming cell, or all cells of the individual's body. Inasmuch as the chromosomes contain the physical basis of the inheritance traits it will be seen that maturation and fertilization yield a new individual which receives half its inheritance traits along with half its chromosomes[2] from each parent. In many of the lower organisms, *e.g.*, fish, frogs, these sex cells are shed into

[1] For a more complete discussion see Chapter XXIII.

[2] The number of chromosomes for each animal is constant: for men it is 48.

the water and there unite. In most of the higher organisms the female sex cells or ova remain within the female organism, and the male sex cells are placed in the reproductive tract and fuse with the ova there.

In the human species, the ovum which is developed in the ovary of the female is fertilized by the entrance into it of a cell known as the *spermatozoön* formed in the testes of the male. (Numerous spermatozoa are placed in the vagina at the mouth of the uterus, and swim upward through the uterus and the Fallopian tubes, in or near which union of a spermatozoön with an ovum takes place.) The fertilized ovum or one-celled embryo[3] is called a *zygote*. After fertilization the zygote divides and subdivides until an enormous number of cells is formed. The cells thus formed arrange themselves in the form of a membrane, *blastoderm*, which is composed of three layers. These layers are known respectively as *ectoderm*, *mesoderm*, and *entoderm*.

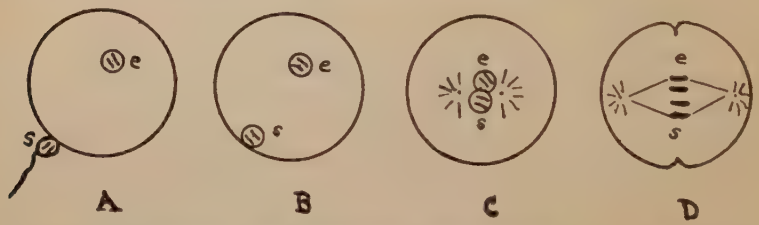


FIG. 11.—DIAGRAMS TO ILLUSTRATE FERTILIZATION OF AN EGG-CELL (OVUM) BY A SPERM-CELL (SPERMATOZOÖN). *A*, *e*, nucleus of a matured egg-cell, showing two chromosomes, *B*, *s*, a sperm-cell, containing two chromosomes. *C*, sperm-cell and egg nucleus united, fertilization complete, normal number of chromosomes established, zygote formed. *D*, initiation of division leading to two-cell stage. (Modified from Bigelow.)

The tissues derived from these primary layers of the blastoderm are as follows:

Ectoderm.—(1) Epidermis and its appendages.

(2) Epithelium of the beginning of the gastropulmonary tract (nose, mouth) and the termination (anus).

(3) Tissues of the nervous system.

Mesoderm.—(1) The connective or supporting tissues.

(2) The muscular tissues.

(3) Tissues of the vascular and lymphatic systems, including endothelium and circulating cells.

(4) Endothelium of a part of the genito-urinary system.

[3] The term embryo is applied to the new organism during the first three months of development. After the third month the term fetus is used.

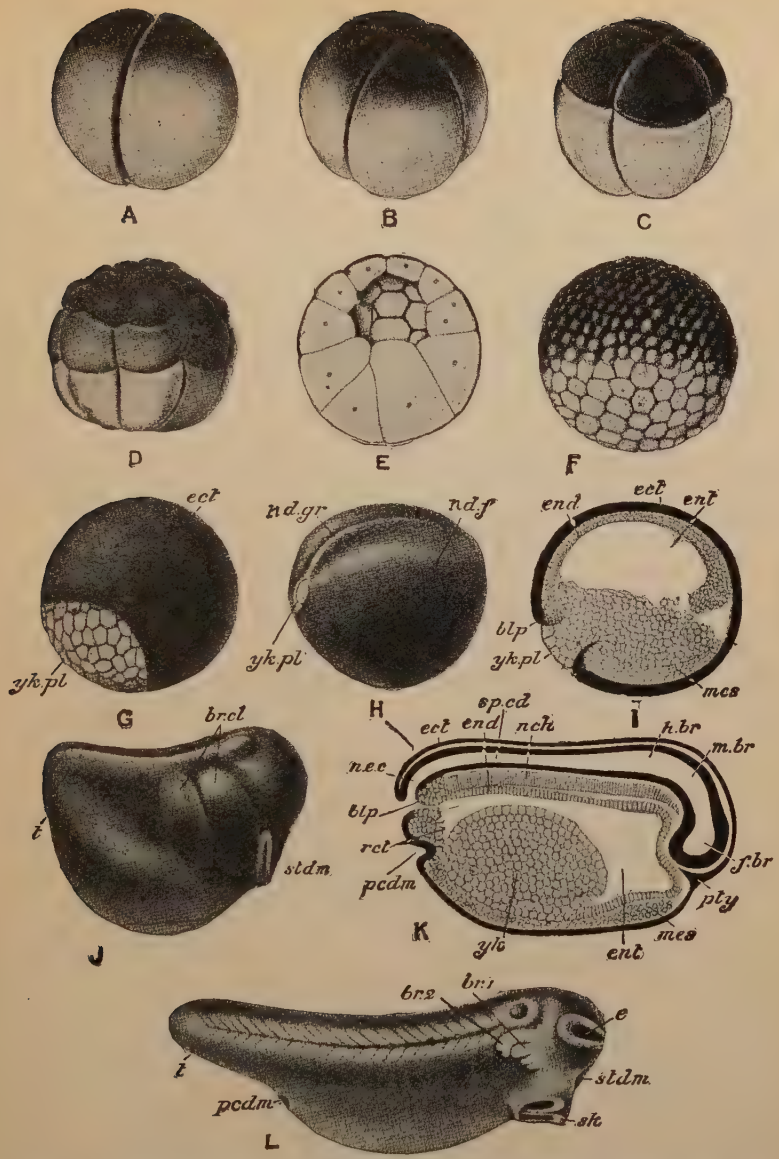


FIG. 12.—DEVELOPMENT OF THE FROG. (Modified from Parker and Haswell's Text-book of Zoology, Vol. II.) *A-F*, segmentation or cleavage. *E* is a section through *D* or *F*, the typical blastula or hollow sac of cells. *G-I*, gastrulation and formation of the three primary tissues, ectoderm, mesoderm and endoderm. *G* and *L*, folding off of organs. *yk. pl.*, yolk plug; *ect*, ectoderm; *ent*, enteron, (digestive canal); *mes*, mesoderm; *blp*, blastophone; *br. cl.*, branchial arches; *stdm*, buccal cavity; *t*, tail; *n. e. c.*, neurenteric canal (closed later; *nch*, notochord (replaced by backbone; *sp. cd.*, spinal cord; *h. br.*, hind brain; *m. br.*, mid-brain; *f. br.*, fore-brain; *pty*, pituitary invagination; *yk*, yolk; *pcdm*, anal canal; *rct*, rectum; *sk*, sucker; *e*, eye; br^1, br^2, gills.

Entoderm.—Epithelium of the gastropulmonary tract except those portions of ectodermic origin at the beginning (mouth, nose) and at the termination (anus).

Gradually as these tissues become differentiated from the three primary tissues, groups of them become folded off by processes of invagination, and evagination, forming the various organs. As the animal grows, these organs increase in size and become differentiated into the systems. The successful working together of the systems produces the higher organism. Reference to H, J, K, and L, of Fig. 12 shows some of the steps of the folding off of the organs in the case of the frog. These diagrams might be taken to illustrate the early steps of development in any type of animal, though the actual appearance of the various types of embryos (human also) would be different due to the quantity of yolk, type of development, etc. For homologies in this very interesting field see any good recent book on embryology.

By the aid of the microscope the different distinct tissues of which the body is formed are found to be comparatively few in number, and some of these, although at first sight apparently distinct, yet have so much in common in their structure and origin, one with another, that the number becomes still further reduced, until we can distinguish only four distinct tissues, *viz.:*

1. The connective tissues.
2. The muscular tissues.
3. The nerve tissues.
4. The epithelial tissues.

CONNECTIVE TISSUE GROUP

These tissues differ considerably in their external characteristics, but are alike (1) in that they all serve to connect and support the other tissues of the body; (2) they are all developed from the mesoderm; (3) the cellular element is at a minimum, and the intercellular material is abundant. The intercellular substance determines the physical character of the tissue. The softness and flexibility of areolar tissue, the toughness of tendon, the hardness of bone, are all due to the character and arrangement of the intercellular substance; (4) with the exception of cartilage, most of the connective tissues are highly vascular; (5) they originate no action but are acted upon by the other tissues. We may therefore group them together as follows:—

1. **Embryonal** tissue.
2. **Areolar** tissue.
3. **Adipose** tissue.
4. **Reticular** tissue.
5. **Fibrous** tissue.
6. **Elastic** tissue.
7. **Cartilage.**
8. **Bone** or **osseous** tissue.

Some histologists classify blood and lymph as varieties of connective tissue known as liquid tissues, though with this difference, the intercellular substance is liquid.

1. Embryonal tissue.—In the development of connective tissue from the mesoderm, the cells unite to form a network with closely-packed nuclei. The cytoplasm increases more rapidly than the nuclei with a resulting differentiation into cells and a primitive semi-fluid intercellular ground substance. This tissue is known as embryonal tissue and is widely distributed throughout the embryo. It represents a stage in the development of connective tissue. Normally it does not occur in the adult, but

FIG. 13.—SUBCUTANEOUS AREOLAR TISSUE FROM A YOUNG RABBIT. (Highly magnified.) The white fibers are in wavy bundles, the elastic fibers form an open network. (Schäfer.)

is the type found in connective tissue repair after injuries and in certain pathological growths. Embryonal tissue in which the ground substance is rich in mucin, is called *mucous connective tissue.* In the mucin or ground substance are found irregular branching cells and small bundles of white fibrils. Some authorities class Wharton's jelly[4] in the umbilical cord, and the vitreous humor[5] found in the posterior chamber of the eye as mucous connective tissue.

2. Areolar tissue.—This tissue is composed of cells varying in shape and size, separated from each other by a semi-fluid ground substance which also contains an irregular network of white

[4] See page 260. [5] See page 485.

fibrous and yellow elastic fibers, which are the predominant characteristic of the tissue.

Function.—Areolar tissue forms web-like binding and supporting material and serves to connect and insulate entire organs. It is found under the skin (subcutaneous), under the mucous membrane (submucous) and filling in the spaces between the blood-vessels and nerves. It is, moreover, continuous throughout the body, and from one region it may be traced without interruption into any other, however distant,—a fact not without interest in practical medicine, seeing that in this way air, water,

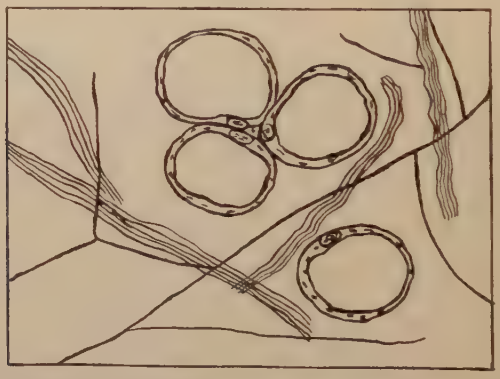


Fig. 14.—Connective Tissue Containing Adipose Cells. (Very highly magnified.) The background is matrix, the fibrous fibers are in wavy bundles, and the elastic fibers are thinner and straighter. Four fat containing cells are shown, the white center representing fat, surrounded by a protoplasmic envelope containing a nucleus.

pus, and other fluids, effused into the areolar tissue, may spread far from the spot where they were first introduced or deposited.

3. Adipose tissue.—Adipose tissue is areolar tissue in which some of the cells are filled with fat. Adipose tissue exists very generally throughout the body accompanying the still more widely distributed areolar tissue in most parts. though not in all, in which the latter is found.

It is found chiefly:

(1) Underneath the skin, in the subcutaneous layer.

(2) Beneath the serous membranes or in their folds.

(3) Collected in large quantities around certain internal organs, especially the kidneys, helping to hold them in place.

(4) Filling up furrows on the surface of the heart.

(5) As padding around the joints.

(6) In large quantities in the marrow of the long bones.

Function.—Adipose tissue (1) constitutes an important reserve fund, which can be returned to the cells by the blood and oxidized, thus producing energy, (2) serves as a jacket or covering under the skin, and being a non-conductor of heat, prevents the too rapid loss of heat through the skin, and (3) serves to fill up spaces in the tissues, thus affording support to delicate structures such as blood-vessels and nerves.

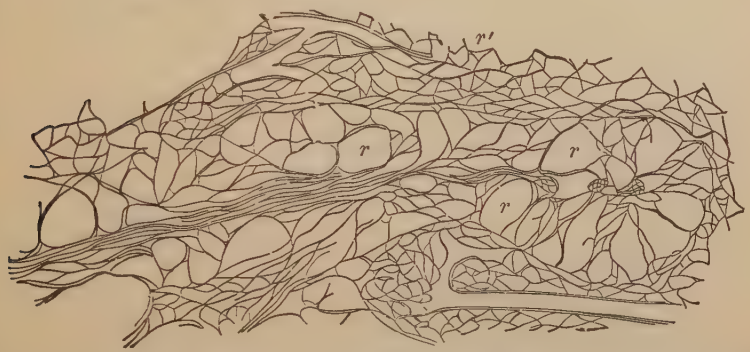


FIG. 15.—RETIFORM TISSUE FROM A LYMPH-NODE. *r*, *r*, *r*, represent open meshes of this tissue. (Quain.)

4. Reticular[6] or retiform tissue.—Reticular tissue is like areolar tissue with a network or reticulum of white fibers. The cells are in the form of broad thin plates wrapped around the fibers.

Lymphoid or adenoid[7] tissue.—This is reticular tissue in which the meshes of the network are occupied by lymph cells. This is the most common condition of retiform tissue.

Function.—Reticular tissue forms a supporting framework in the lymph-nodes, in bone marrow and in muscular tissue. It is also present in the spleen, in the mucous membrane of the gastro-intestinal tract, in the lungs, liver and kidneys.

5. Fibrous tissue.—This tissue consists almost wholly of wavy white fibers, which cohere very closely and are arranged side by side in bundles which have an undulating outline. The spaces between the bundles are occupied by cells arranged in rows, but the cells are not a prominent feature of this tissue.

Fibrous tissue is white, strong and tough, yet perfectly pliant; but it is almost devoid of extensibility and is very sparingly supplied with nerves and blood-vessels.

[6] Reticulum (from the Latin *reticulum*, "a small net"). Resembling a small net.

[7] Adenoid (from the Greek *aden*, "a gland," and *eidos*, "resemblance"). Pertaining to or resembling a gland.

Function.—Fibrous tissue is met with in the form of:—

(1) *Ligaments.*—Ligaments are strong flexible bands, or capsules, of fibrous tissue that help to hold the bones together at the joints. (See Figs. 63 and 118.)

(2) *Tendons or sinews.*—Tendons are white glistening cords or bands which serve to attach the muscles to the bones. (See Fig. 118.)

(3) *Aponeuroses.*—Aponeuroses are flat, wide bands of fibrous tissue which serve to connect one muscle with another. (See Fig. 77.)

(4) *Protecting sheaths or membranes.*—Fibrous tissue is found investing and protecting different organs of the body. Examples —heart and kidneys.

FIG. 16.—FIBROUS TISSUE FROM THE LONGITUDINAL SECTION OF A TENDON. The spaces between the bundles of fibers are occupied by rows of cells. (Gegenbauer.)

(5) *Fasciæ.*—The word *fascia* means a band or bandage. It is most frequently applied to sheets of fibrous membrane which are wrapped around muscles, and serve to hold them in place. Fasciæ are divided into two groups, associated with the skin and the muscles. They are called: *a.* Superficial, and *b.* Deep.

a. Superficial fasciæ.—The subcutaneous areolar tissue, which forms a nearly continuous covering beneath the skin, is classed as superficial fasciæ. It varies in thickness, and usually permits free movement of the skin on the subjacent parts.

Infection of the superficial fasciæ is called *cellulitis.* In this loose areolar tissue infection spreads readily and it is difficult to keep it from extending to surrounding areas.

b. Deep fasciæ.—The deep fasciæ are sheets of white, flexible fibrous tissue, employed to envelop and bind down the muscles, also to separate them into groups.[8] The term *fasciæ*, unless limited by an adjective, is usually employed to designate the *deep fasciæ.* Subcutaneous areolar tissue is rarely called by the name fascia, though it is correctly classed as such.

[8] See page 76.

6. Elastic tissue.—When the elastic fibers predominate they give a yellowish color to the tissue, and it is known as elastic. This form of connective tissue is extensile and elastic in the highest degree, and wherever located, does such work as India rubber would do, but it is not so strong as the fibrous variety.

Function.—Elastic tissue has a most important use in assisting muscular tissue, and so lessening the wear and tear of muscle. It is found:—

(1) Between the laminæ of adjacent vertebræ. (*Ligamenta flava.*)[9]

(2) In the walls of the blood-vessels (especially arteries), bronchial tubes, and vocal cords.

(3) Entering into the formation of the lungs and uniting the cartilages of the larynx.

Areolar, fibrous and elastic tissue agree closely with one another in elementary structure. It is the different arrangement of the cells and fibers, and the relative proportion of one kind of fiber to the other, that gives them their different characteristics.

7. Cartilage.—This is the well-known substance called *gristle.* It is firm, tough and elastic. When a very thin section is examined with a microscope, it is seen to consist of groups of cells in a mass of intercellular substance called the matrix. According to the amount and texture of the intercellular substance, we distinguish three principal varieties:—

(1) *Hyaline or true cartilage.*

(2) *White fibrocartilage.*

(3) *Yellow or elastic cartilage.*

Hyaline cartilage.—This variety is named from the Greek word for glass. A comparatively small number of cells are embedded in an abundant quantity of intercellular substance which appears homogeneous, but is made up of fibers quite similar to those found in fibrous connective tissue.

1. Hyaline cartilage covers the ends of the bones in the joints, where it is known as articular cartilage.

2. Hyaline cartilage forms the rib cartilages, where it is known as costal cartilage.

In both these situations the cartilages are in immediate connection with bone, and may be said to form part of the skeleton, hence are frequently described as skeletal cartilages.

Function.—In covering the ends or surfaces of bones in the joints, the articular cartilages provide these harder parts with a

[9] See page 54.

thick, springy coating, which breaks the force of concussion, and gives ease to the motion of the joints. In forming part of the solid framework of the thorax or chest, the costal cartilages impart elasticity to its walls. Hyaline cartilage enters into the formation of the nose, ear, larynx, and trachea.

In the embryo a type of hyaline cartilage known as embryonal cartilage, forms the matrix in which most of the bones are developed.

White fibrocartilage.—The intercellular substance is pervaded with bundles of white fibers, between which are scattered cartilage cells. It closely resembles white fibrous tissue.

White fibrocartilage is found joining bones together, the most familiar instance being the flat round plates or discs of fibrocartilage connecting the bodies of the vertebræ and the pubic bones. In these cases the part in contact with the bone is always hyaline cartilage, which passes gradually into the fibrocartilage.

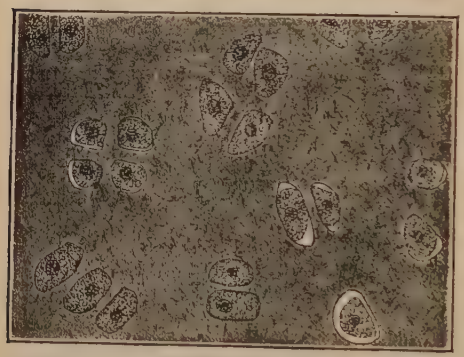


FIG. 17.—Cartilage from hip joint of frog. Groups of cartilage cells in an apparently homogeneous matrix. (Bailey.)

Function.—It serves as a strong, flexible, connecting material between bones and is found wherever great strength combined with a certain amount of rigidity is required.

Yellow, or elastic, cartilage.—The intercellular substance is pervaded with yellow elastic fibers which form a network. In the meshes of the network the cartilage cells are found.

Yellow, or elastic, cartilage is found in the epiglottis, cartilages of the larynx, Eustachian tube, and external ear.

Function.—It strengthens and maintains the shape of these organs, and yet allows of a certain amount of elasticity.

Cartilage is not supplied with nerves, and very rarely with blood-vessels.

Nearly all cartilages receive their nourishment from the *perichondrium*, a moderately vascular fibrous membrane which covers them.

8. Bone, or osseous, tissue.—Bone is connective tissue in which

the intercellular substance derived from the cells is rendered hard by being impregnated with mineral salts, chiefly the phosphate and the carbonate of calcium. These salts are intimately associated and combined with the structure of bone, as is shown by the fact that though they compose two-thirds of the weight of the bone, they cannot be seen even by the use of high-power lens. The inorganic matter can be dissolved out by soaking a bone in dilute acid for several days, or the organic matter may be driven off by heat, but in both cases the shape of the bone will be preserved. Bone freed from inorganic matter is a tough, flexible, elastic substance, so free from stiffness that it can be tied in a knot. Bone freed from organic matter is white, rigid, and so brittle it can be crushed in the fingers.

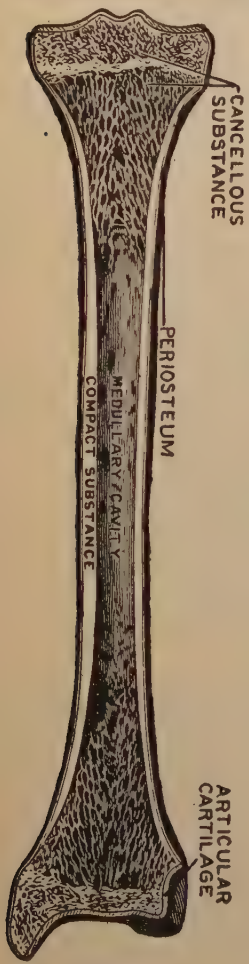


FIG. 18.—VERTICAL SECTION OF A LONG BONE. (Gerrish.)

Structure of Bone.—On sawing a bone it will be seen that in some parts it consists of slender fibers and lamellæ which form a structure resembling lattice-work, whilst in others it is dense and close in texture, appearing like ivory. We thus distinguish two forms of bony tissue:—

FIG. 19.—Section through the upper end of femur showing cancellated structure of the bone. (Zaaijer.)

(1) *The cancellated, or spongy.*

(2) *The dense, or compact.*

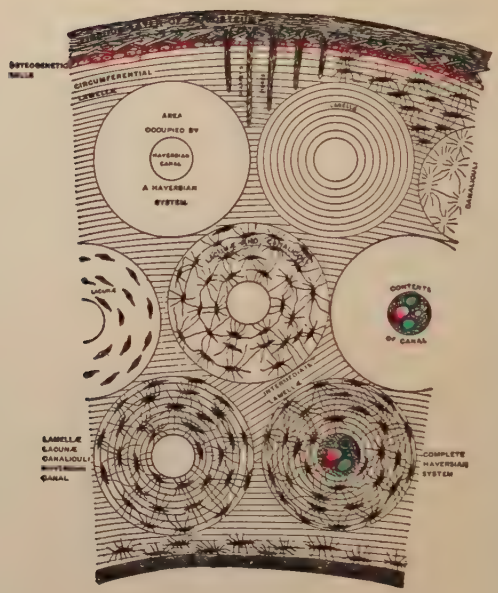


Fig. 20.—Diagram of the Structure of Osseous Tissue. With the details drawn to a very much larger scale than the complete drawing. A small part of a transverse section of the shaft of a long bone is shown. At the uppermost part is the periosteum covering the outside of the bone; at the lowermost part is the endosteum lining the marrow cavity. Between these is the compact tissue consisting largely of a series of Haversian systems, so named from Havers, a celebrated anatomist, each being circular in outline and perforated by a central canal. In the first one is shown only the area occupied by a system; in the second is seen the concentric arrangement of the lamellæ; in the others, respectively, the tiny wavy canals called canaliculi; the lacunæ which contain the bone cells; lacunæ and canaliculi; the contents of the canal, artery, vein, lymphatic, and areolar tissue; lamellæ, lacunæ, and canaliculi; and finally all of the structures composing a complete system. Between the systems are circumferential and intermediate lamellæ, only a few of which are represented as lodging lacunæ, though it is to be understood that lacunæ are in all parts. The periosteum is seen to be made up of a fibrous layer and a vascular layer, and to have upon its attached surface a stratum of cells. From the fibrous layer project inward the rivet-like fibers of Sharpey. (Gerrish.)

On closer examination, it will be seen that the bony matter is everywhere porous, and the difference between the two is only a matter of degree. The compact tissue has fewer spaces and more solid matter between them, while the cancellated has larger cavities and more slender intervening bony partitions. In all bones the compact tissue is the stronger; it lies on the surface of the bone and forms an outer shell or crust, whilst the lighter, spongy tissue is contained within. The shafts of the long bones are made up almost entirely of the compact substance, except that they are hollowed out to form a central canal,—the medullary canal,—which has a fibrous lining called *endosteum*, and contains marrow.

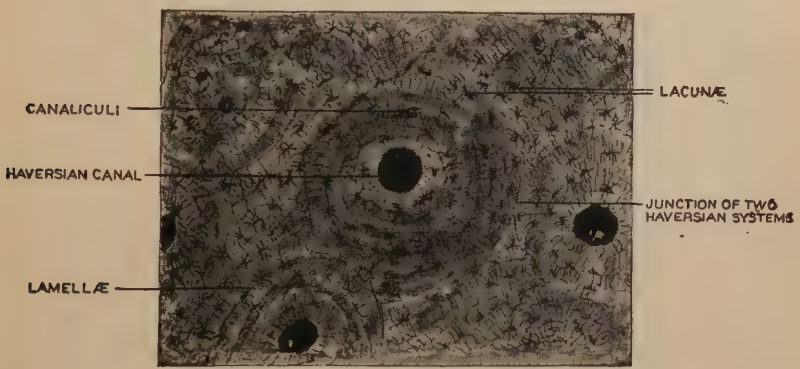


FIG. 21.—TRANSVERSE SECTION OF OSSEOUS TISSUE.

Marrow.—There are two distinct kinds of marrow, red and yellow.

Red marrow consists of (1) a small amount of fibrous tissue that acts as a support for a large number of blood-vessels, (2) a large number of marrow cells or *myelocytes*, which resemble the white blood cells, (3) a small number of fat-cells, (4) a number of cells called *erythroblasts* from which the red blood cells are derived.[10] It is found in the marrow cavity at the ends of the long bones and in the cancellous tissue.

Yellow marrow contains more connective tissue and fat cells than red marrow, but it has fewer myelocytes, and after birth contains few if any red blood cells. It is found in the medullary canals of the long bones and supports the blood-vessels, lymph-vessels and nerves that traverse these canals. The white cells of the blood and lymph are derived from its myelocytes.

[10] See page 187.

Periosteum.—All bones are covered, except at the joints, by a vascular fibrous membrane, the periosteum (around the bone). It consists of an outer fibrous layer and an inner vascular layer. The attachment of the periosteum to bone is rendered firmer by inward prolongations of the fibrous layer called the *fibers of Sharpey*.

Blood-vessels.—Unlike cartilage, the bones are plentifully supplied with blood. If we strip the peiosteum from a fresh bone, we see many bleeding points representing the canals (Volkmann's) through which the blood-vessels enter and leave the bone. These blood-vessels proceed from the periosteum to join the system of Haversian canals. Around the Haversian canals the lamellæ are disposed while lying between them, arranged in circles, are found the lacunæ, which contain the bone cells. Running from one lacuna to another in a radial direction through the lamellæ towards the center are the canaliculi. Following this scheme, it will be seen that the innermost canaliculi run into the Haversian canals, and thus is established a direct communication between the blood in these canals and the cells in the lacunæ connected with and surrounding each Haversian canal. The marrow in the body of a long bone is supplied by one large artery (sometimes more)—called the *medullary* or *nutrient* artery, which enters the bone at the nutrient foramen, situated in most cases near the center of the body, and perforates the compact tissue obliquely. It sends branches upward and downward which ramify in the marrow, and enter the adjoining bony tissue. The twigs of these vessels anastomose with the arteries of the compact and cancellous tissue. In this way the whole substance of the bone is penetrated by intercommunicating channels, and the nutrient matters and mineral salts from the blood can find their way to every part. In most of the flat, and in many of the short spongy bones, larger apertures give entrance to vessels which pass to the central parts of the bone and correspond to the nutrient arteries of long bones.

Development of bones.—In the early embryo, some bones, such as those forming the roof and sides of the skull, are preformed in membrane; others, such as those of the limbs, are preformed in rods of cartilage covered by membrane. Hence two kinds of ossification occur, the intramembranous, and the intracartilaginous.

In *intramembranous ossification* the membrane which occupies the place of the future bone is of the nature of connective tissue

and ultimately forms the periosteum; it is composed of fibers and granular cells, called *osteoblasts* with an intervening ground substance. When bone begins to form a network of spicules radiates from the point or center of ossification. These spicules develop into fine fibrils comparable to those of white fibrous tissue. The membrane soon assumes a granular appearance from the deposit of calcareous granules in the fibers, and in the intervening matrix. The involved osteoblasts form the cells of the future bone and the spaces in which they are enclosed are the *lacunæ*. As the fibers grow out they continue to calcify, and give rise to fresh bone spicules. Thus a network of bone is

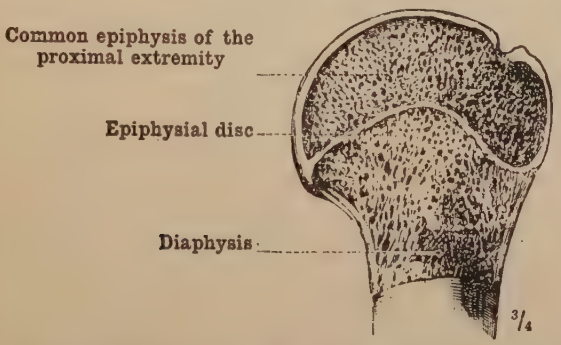


FIG. 22.—The common epiphysis of the proximal extremity of the humerus, from a boy thirteen years. (Toldt, Atlas of Human Anatomy.)

formed, the meshes of which contain the blood-vessels, and a delicate connective tissue crowded with osteoblasts. The bony network thickens by the addition of fresh layers of bone formed by the osteoblasts and the meshes are correspondingly encroached upon. Successive layers of bony tissue are deposited under the periosteum so that the bone increases much in thickness, and presents the structure of compact bone.

In *intracartilaginous ossification* which usually occurs in long bones which are preformed in cartilage, the process commences in the center and proceeds toward the extremities. Thus there are three centers of ossification, one for the shaft called *diaphysis*, and one for each extremity called *epiphysis*. Ossification proceeds from the diaphysis toward the epiphysis, and from the epiphysis toward the diaphysis. As each new portion is ossified thin layers of cartilage continue to develop between the diaphysis and epiphysis and during the period of growth, these outstrip ossification. When this ceases the growth of a bone stops.

While this process is in progress, ossification proceeds by the intramembranous method and the membrane covering the cartilage called *perichondrium* becomes highly vascular and assumes the character of periosteum. From this membrane a layer of bone develops, and is deposited between the bone and the membrane, thus providing compact bone on the surface. The growth in the thickness of bone is accomplished by the addition of layer after layer of compact bone underneath the periosteum.

Ossification begins before birth in all bones except the coccyx, the carpal bones, and the four tarsal bones (calcaneus, talus, cuboid and navicular); but many bones remain in two or more pieces during childhood and youth.

From this brief discussion two points of practical interest stand out, (1) the bones of the new-born infant are soft and largely composed of cartilage; (2) since the process of ossification is going on continually, the proper shape of the cartilage should be preserved in order that the shape of the future bone may be normal. Therefore it is obvious that a young baby's back should be supported, and a child should always rest in a horizontal position. The facility with which bones may be moulded and become misshapen is seen in the flattening of the head of some Indians who bind a board across the top of the infant's skull; in the bow legs of children, and in the distortion of the feet of Chinese ladies of the old régime. However, the softness of the skeleton of a child accounts for the fact that the many jars and tumbles experienced in early life are not as injurious to the jelly-like frame as they would be to a harder structure.

Numerous experiments have demonstrated that the proper ossification and growth of bone depend upon (1) the presence of calcium carbonate and phosphate in the food, and (2) the presence of chemical substances which enable the bone cells to utilize the lime and other food derivatives for the formation of bone. These chemical substances may be derived from the body secretions[11] or from food. The latter are called vitamins.[12] Lime is present in milk to the extent of 0.15 per cent, and consequently milk is a necessary food for growing children.

Rickets or rachitis.—This is a disease of childhood and is due to lack of sunshine and lack of the substances required for the ossification of bone. The bones are soft and become misshapen, resulting in bow-legs and malformations of the head, chest[13] and

[11] See page 283.] [12] See page 368.

[13] One of the early findings is the so-called rachitic rosary, a name given to enlargements of the costal cartilages at their junction with the ribs.

pelvis. Sunlight and proper diet are important factors in the prevention and cure of rickets. Cod-liver oil is a specific.

Fracture.—The term *fracture* is applied to the breaking of a bone which may be either partial or complete. As a result of the greater amount of organic matter in the bones of children, they are flexible, bend easily, and do not break readily. In some cases the bone bends like a bough of green wood. Some of the fibers may break, but not the whole bone, hence the name *green-stick fracture*. The greater amount of inorganic matter in the bones of the aged renders the bones more brittle, so that they break easily and heal with difficulty.

Regeneration of bone.—A fracture is usually accompanied by injury to the periosteum and tissues. This results in inflammation, which means that an increased amount of blood is sent to the part. The plasma and white blood cells from the blood exude into the tissues and form a viscid substance, which sticks the ends of the bone together, and is called *callus*. Usually bone cells from the periosteum and lime salts are gradually deposited in the callus, which eventually becomes hardened and forms new bone. Occasionally the callus does not ossify and a condition known as *fibrous union* results. The periosteum is largely concerned in the process of repair; for if a portion of the periosteum be stripped off, the subjacent bone will be liable to die, while if a large part or the whole of a bone be removed, and the periosteum at the same time left intact, the bone will wholly or in a great measure be regenerated.

SUMMARY

New cells arise from pre-existing cells. New individuals arise from pre-existing individuals.

- **Reproduction**
  - **Function**—Produce another being.
  - **Accomplished in two ways**
    - **Asexually**
      1. Divide into two or more, *e.g.*, budding of plants and animals.
      2. Divide in two directly or by mitosis.
      3. Divide into spores.
    - **Sexually**
      1. Individuals make sex cells (gametes).
         - (*a*) In lower organisms shed in water and unite.
         - (*b*) In higher organisms gamete retained by female, and male gamete is placed in reproductive tract of female.

Origin of Tissues

- (*a*) **Maturation**—Reduction of original number of chromosomes in gamete to one-half.
- (*b*) **Fertilization**—Union of male and female gametes. Number of chromosomes restored to original number.
- (*c*) **Multiplication of cells.**
- (*d*) **Formation of Blastoderm**

Ectoderm	Epidermis and its appendages.
	Epithelium of the beginning of gastropulmonary tract (nose, mouth) and the termination (anus).
	Tissues of the nervous system.
Mesoderm	The connective or supporting tissues.
	The muscular tissues.
	Tissues of the vascular and lymphatic systems, including endothelium and circulating cells.
	Endothelium of a part of the genito-urinary system.
Entoderm	Epithelium of the gastropulmonary tract except those portions of ectodermic origin at the beginning (mouth, nose), and at the termination (anus).

Classification of Tissues—Connective. Muscular. Nerve. Epithelial.

Connective Tissue.—A tissue of cells with a great deal of intercellular substance, which is derived from the cells.

Characteristics

1. Serves to connect and support other tissues.
2. All are developed from the mesoderm.
3. Cellular element at a minimum, intercellular element abundant.
4. With the exception of cartilage, all are highly vascular.
5. They originate no action, but are acted upon by other tissues.

Varieties

Embryonal.	Reticular.	Cartilage.
Areolar.	Fibrous.	Bone.
Adipose.	Elastic.	Liquid.

Embryonal Tissue.—Represents a stage in development of connective tissue. Consists of cells and a primitive intercellular ground substance. When ground substance is rich in mucin is called mucous connective tissue.

Areolar tissue.—Formed by interlacing of wavy bundles of white fibers and some straight elastic fibers with cells lying in the ground substance.

Function.—Connects, insulates, forms protecting sheaths, and is continuous throughout the whole body.

Adipose tissue.—Modification of areolar tissue, with cells filled with fat. Distribution quite general but not uniform.

Function

1. Forms a reserve fund for the production of energy.
2. Prevents the too rapid loss of heat.
3. Serves to protect and support delicate organs.

Reticular tissue.—Is areolar tissue with a network of white fibers. Cells wrapped around fibers.

Lymphoid tissue. —Reticular tissue with meshes of network occupied by lymph cells.

Function.—Reticular tissue forms a supporting framework in many organs, *e.g.*, lymph-nodes, bone marrow and muscular tissue. Reticular tissue is present in the spleen, mucous membrane of the gastro-intestinal tract, lungs, liver and kidneys.

Fibrous tissue.—Formed of wavy bundles of white fibers only, with cells in rows between bundles. Very strong and tough but pliant.

Function.—Is found in form of ligaments, tendons, aponeuroses, protecting sheaths, and fasciæ.

Elastic tissue.—Formed of yellow elastic fibers with few bundles of white fibers. It is extensile and elastic.

Function.—Serves same purpose as India rubber. Saves wear and tear of muscles. Found in ligamenta flava, blood-vessels, air tubes, vocal cords, lungs, and larnyx.

Cartilage.—Cartilage consists of a group of cells in a matrix. It is firm, tough and elastic, covered and nourished by perichondrium.

Varieties
- **1. Hyaline cartilage.** (Articular / Costal) Skeletal.
- **2. White fibrocartilage.**
- **3. Yellow elastic cartilage.**

Bone, or osseous tissue.—Bone is connective tissue in which the intercellular substance derived from the cells is rendered hard by being impregnated with mineral salts.

Liquid tissues.—Cells in a liquid intercellular substance, *e.g.*, blood and lymph.

BONE OR OSSEOUS TISSUE

Composition
- Mineral matter
  - Calcium phosphate.
  - Calcium carbonate.
  - Small portion of other salts.
- Organic matter
  1. Ground substance.
  2. Bone cells.
  3. Blood-vessels.
  4. Connective tissue.
  5. Marrow.

Varieties
- Cancellated or spongy.
- Dense or compact like ivory.

Canals
- Medullary—Red and yellow marrow.
- Haversian (Blood-vessels. / Lymphatics.)

Haversian system
- Haversian canals, branch freely and connect system to system.
- Lamellæ—bony fibers arranged in rings around Haversian canals.
- Lacunæ—lymph spaces between lamellæ occupied by bone cells.
- Canaliculi—canals which radiate from lacunæ to the Haversian canals.

Endosteum—A fibrous membrane that lines the medullary canal.

Marrow
- **Red**—Consists of fibrous tissue supporting blood-vessels, myelocytes, fat cells and erythroblasts from which red blood cells are derived. Found in the marrow cavity at the end of long bones and in cancellous tissue.
- **Yellow**—Contains more connective tissue and fat cells than red marrow, fewer myelocytes, and few if any red cells. White cells of blood and lymph are derived from its myelocytes. Found in the medullary canals of the long bones.

Periosteum.—A vascular fibrous membrane that covers the bones and serves to nourish them. Important in reunion of broken bone and growth of new bone.

Fibers of Sharpey.—Inward prolongations of periosteum.

Blood-vessels.—Twigs of nutrient artery in medullary canal anastomose with twigs from Haversian canals, and these in turn anastomose with others which enter from periosteum.

Development of bone
- In the embryo bones are preformed in membrane and cartilage.
- **Ossification**
  - Intramembranous.
  - Intracartilaginous.
- **Dependent upon**
  - Calcium carbonate and phosphate.
  - Chemical substances from secretions and food.

CHAPTER IV

THE SKELETON.—DIVISIONS OF THE SKELETON; BONES OF THE CRANIUM; BONES OF THE FACE; BONES OF THE TRUNK; BONES OF THE UPPER EXTREMITIES; BONES OF THE LOWER EXTREMITIES

Function.—The bones are the principal organs of support, and the passive instruments of locomotion. Connected together in the skeleton, they form a framework of hard material, affording attachment to the soft parts, maintaining them in their due position, sheltering such as are of delicate structure, giving stability to the whole fabric, and preserving its shape.

The entire skeleton in the adult consists of two hundred and six named bones. These are:—

Cranium	8	206
Face	14	
Ear (Malleus 2, Incus 2, Stapes 2)	6	
Hyoid	1	
The spine, or vertebral column (sacrum and coccyx included)	26	
Sternum and ribs	25	
Upper extremities	64	
Lower extremities	62	

In this enumeration the sesamoid[1] and Wormian bones are not included. Sesamoid bones are found embedded in the tendons covering the bones of the knee, hand and foot.

Wormian bones are small isolated bones which occur in the course of the sutures, most frequently the lambdoidal suture. (See Figure 61.)

Classification.—The bones may be divided, according to their shape, into four classes: 1. *Long*, 2. *Short*, 3. *Flat*, and 4. *Irregular*.

A long bone consists of a shaft and two extremities. The shaft is formed mainly of compact tissue, this compact tissue being thickest in the middle, where the bone is most slender and the strain greatest, and it is hollowed out in the interior to form the *medullary canal*. (See Fig. 18.) The extremities are made of cancellated tissue with only a thin coating of compact substance, and are more or less expanded for greater convenience of mutual

[1] Ses'amoid [from the Greek *sesamon*, a "seed of the sesamum," and *eidos*, "form," "resemblance"], resembling a grain of sesamum.

connection, and to afford a broad surface for muscular attachment. All long bones are more or less curved, which gives them greater strength. They are found in the extremities, *e.g.*, humerus.

The *short bones* are small pieces of bone irregularly shaped. Their texture is spongy throughout, excepting at their surface, where there is a thin crust of compact substance. The short bones are the sixteen bones of the carpus, the fourteen bones of the tarsus, and the two patellæ.

Where the principal requirement is either extensive protection or the provision of broad surfaces for muscular attachment, we find *flat bones*. The bony tissue expands into broad or elongated flat plates which are composed of two thin layers of compact tissue, enclosing between them a variable quantity of cancellous tissue, *e.g.*, occipital bone.

The *irregular bones* are those which, on account of their peculiar shape, cannot be grouped under either of the preceding heads. The vertebræ are a good example. The bones of the ear are so small that they are described as *ossicles* and do not fit in any of these groups.

Processes and depressions.—If the surface of any bone is examined, certain projections and depressions are seen. The projections are called *processes*. The depressions are called *fossæ* or *cavities*, and either a qualifying adjective is used to describe them, or a special name given to them. Processes and depressions are classified as: **1. Articular, 2. Non-articular.** The articular are provided for the mutual connection of bones to form joints. The non-articular serve for the attachment of ligaments and muscles. The following terms are used:—

Cavities.—The terms *sinus*[2] and *antrum* are applied to cavities within certain bones.

Condyle.—A rounded or knuckle-like process.

Crest.—A narrow ridge of bone.

Fissure.—A narrow slit.

Foramen.—A hole or orifice through which blood-vessels, nerves, and ligaments are transmitted.

Fossa.—A depression in or upon a bone.

Groove or sulcus.—A furrow.

Head.—A portion supported on a constricted part or neck.

Meatus or Canal.—A long tube-like passageway.

Process.—Any marked bony prominence.

Spine or Spinous Process.—A sharp, slender process.

Trochanter.—A very large process.

Tubercle.—A small rounded process.

Tuberosity.—A large rounded process.

[2] The term "sinus" is also used in surgery to denote a narrow tract leading from the surface down to a cavity.

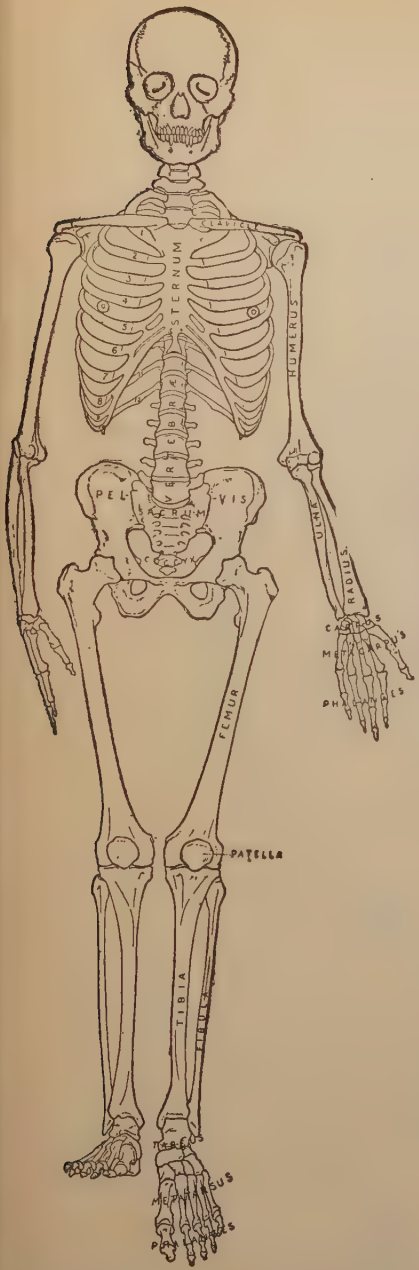


FIG. 23.—THE HUMAN SKELETON (Front View).

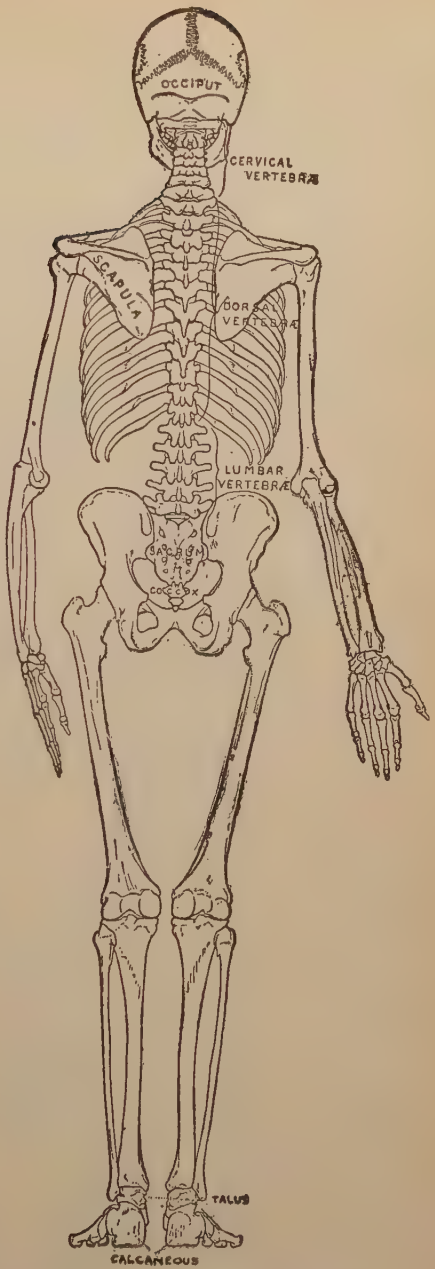


FIG. 24.—THE HUMAN SKELETON (Back View).

Courtesy of William Wood & Co., and John Bale Sons & Danielsson, Ltd.

DIVISIONS OF THE SKELETON

In taking up the various divisions of the skeleton, we will consider it as consisting of—

Axial Skeleton	1. Head or skull	Cranium. Face.
	2. Hyoid.	
	3. Trunk	Vertebræ. Sternum. Ribs.
Appendicular Skeleton	4. Upper extremities.	
	5. Lower extremities.	

The head or skull.—The head or skull rests upon the spinal column, and is formed by the union of the cranial and facial

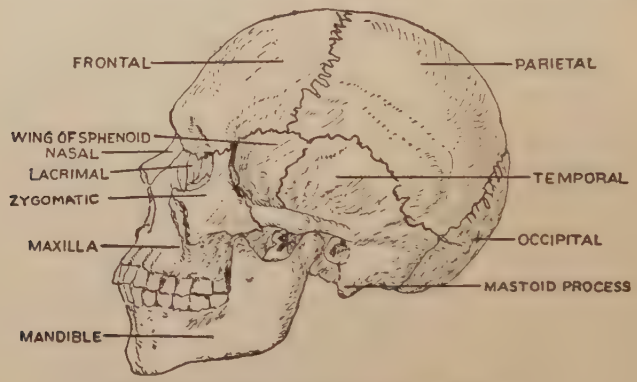


FIG. 25.—SIDE VIEW OF THE SKULL.

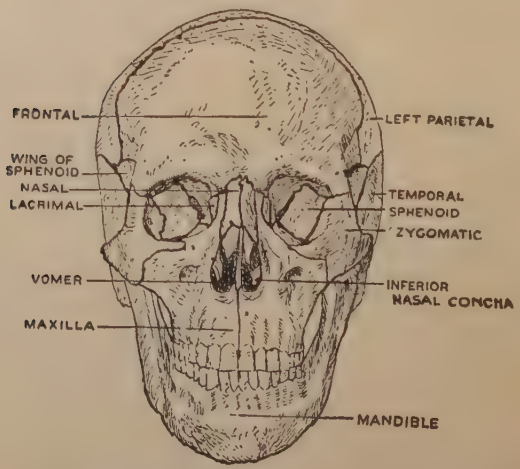


FIG. 26.—FRONT VIEW OF THE SKULL.

bones. It is divisible into—1. **Cranium,** or **brain case,** and 2. **Anterior region,** or **face.**

BONES OF THE CRANIUM

Occipital, base of skull	1	8
Parietal, crown	2	
Frontal, forehead	1	
Temporal, ear region	2	
Ethmoid, between cranial and nasal cavities	1	
Sphenoid, base of brain and back of orbit	1	

Occipital bone.—It is situated at the back and base of the skull. The internal surface is deeply concave, and presents many

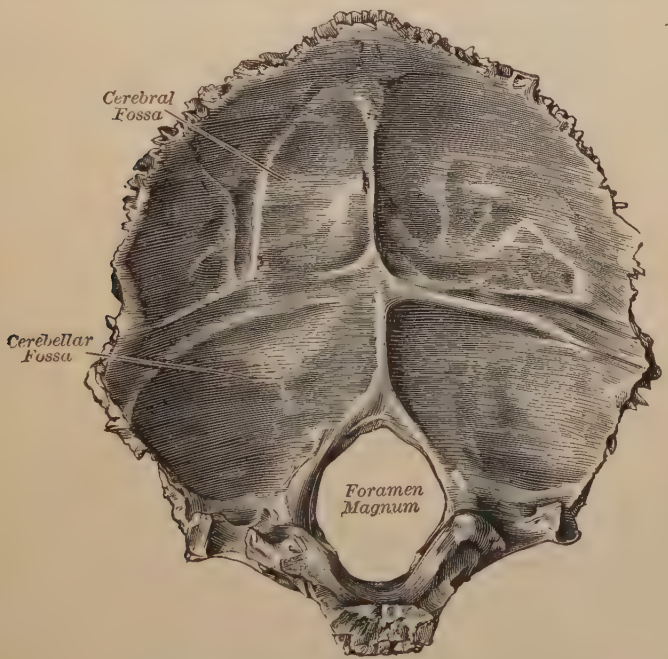


FIG. 27.—OCCIPITAL BONE. Inner surface.

eminences and depressions for the reception of parts of the brain. There is a large hole—the *foramen magnum*—in the inferior portion of the bone, for the transmission of the medulla oblongata (the constricted portion of the brain) where it narrows down to join the spinal cord. At the sides of the foramen magnum it presents two processes called condyles, which articulate with the first vertebra.

Parietal bones.—The right and left form by their union the greater part of the sides and roof of the skull. The external sur-

face is convex and smooth; the internal surface is concave, and presents eminences and depressions for lodging the convolutions of the brain, and numerous furrows for the ramifications of arteries which supply the dura mater (membrane which covers the brain) with blood.

Frontal bone.—It resembles a cockle shell, and not only forms the forehead, but also enters into the formation of the roof of the orbits, and of the nasal cavity. The arch formed by part of the frontal bone over the eye is sharp and prominent, and is known as the supraorbital margin. Just above the supraorbital margins are hollow spaces called the *frontal sinuses* (see Figs. 28 and 34) which are filled with air and open into the nose. In the upper and

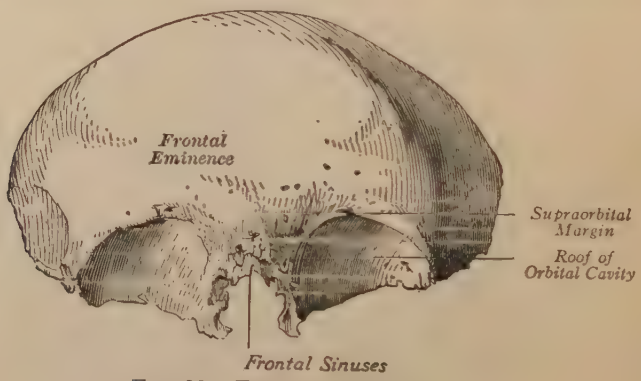


Fig. 28.—Frontal Bone.

outer angle of each orbit are two depressions called lacrimal fossæ for the reception of the glands of the same name, which secrete the tears. At birth the bone consists of two pieces, which afterwards become united along the middle line, by a suture (See Figs. 60 and 61) which runs from the vertex of the bone to the root of the nose. This suture usually becomes obliterated within a few years after birth, but it occasionally remains throughout life.

Temporal bones.—The right and left are situated at the sides and base of the skull. They are named temporal from the Latin word *tempus*, time, as it is on the temples the hair first becomes gray and thin, and thus shows the ravages of time. The temporal bones are divided into three parts—the hard, dense portion, called *petrous;* a thin and expanded scale-like portion, called *squamous*; and a mastoid portion, which is prolonged downward and forms the *mastoid process.* This process is filled with a number of connected cancellous spaces, containing air, and

called **mastoid cells.**[3] They communicate with the cavity of the middle ear. The condition known as mastoiditis means inflammation of the lining of these cells.

The internal ear, the essential part of the organ of hearing, is contained in a series of cavities, channeled out of the substance of the petrous portion. Between the squamous and petrous portions is a socket, called the *glenoid fossa*, for the reception of the condyle of the lower jaw.

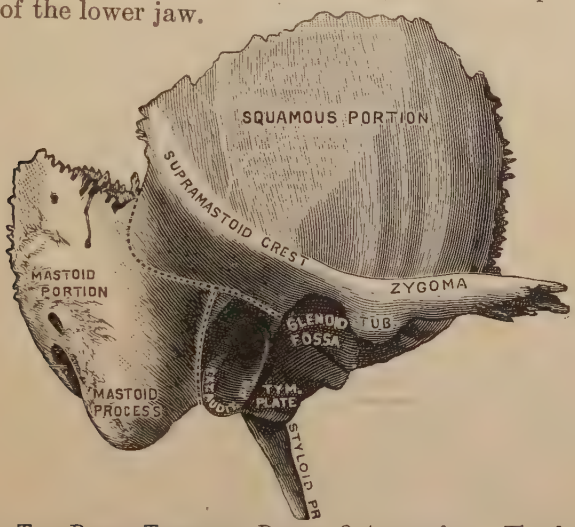


FIG. 29.—THE RIGHT TEMPORAL BONE. Outer surface. The dotted lines indicate the lines of suture between squamous, mastoid, and petrous portions. (Gerrish.)

Ethmoid bone.—It is an exceedingly light cancellous bone consisting of a horizontal or cribiform plate, a perpendicular plate (See Fig. 30) and two lateral masses or labyrinths. The horizontal plate forms the roof of the nasal cavity and closes the anterior part of the base of the cranium. It is pierced by numerous foramina or holes, through which the olfactory nerves pass to the mucous membrane of the nose. Descending from the horizontal plate is the perpendicular plate which helps to form the upper part of the nasal septum. On either side the lateral masses form part of the orbit and part of the corresponding nasal cavity. The lateral masses contain a number of thin-walled cavities called the ethmoidal sinuses, which communicate with the nasal

[3] Cells.—The student must bear in mind that the word cell is used with two different meanings in anatomy. Histologically speaking, the word "cell" refers to one of the component units of the body, such as an "epithelial cell" or "nerve cell."

In connection with the use of the words "mastoid cells" in the text, the word "cells" refers to tiny enclosed hollow chambers.

cavity. Descending from the horizontal plate on either side of the septum are two processes of very thin, cancellous, bony tissue, named the superior and middle conchæ. (See Fig. 179.)

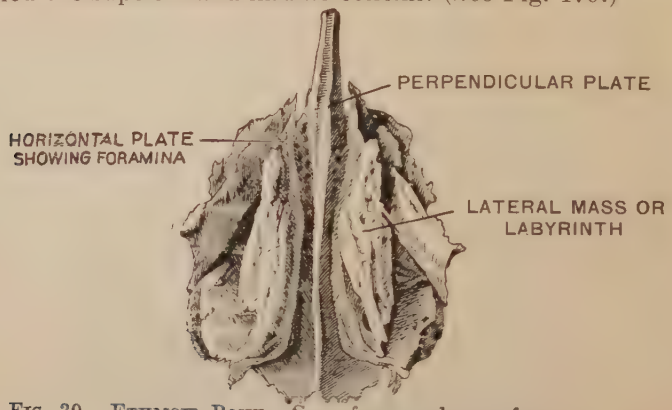


FIG. 30.—ETHMOID BONE. Seen from under surface.

Sphenoid bone.—It is situated at the anterior part of the base of the skull and binds the other cranial bones together. It helps to form the cavities of the cranium, orbits, and nose. In form it somewhat resembles a bat with extended wings, and is described as consisting of a body, two pairs of wings, and two pterygoid processes which projects from it below. The body is joined to the ethmoid in front and the occipital behind. It contains cavities which are called sphenoidal sinuses. (See Fig. 34.) They communicate with the naso-pharynx.

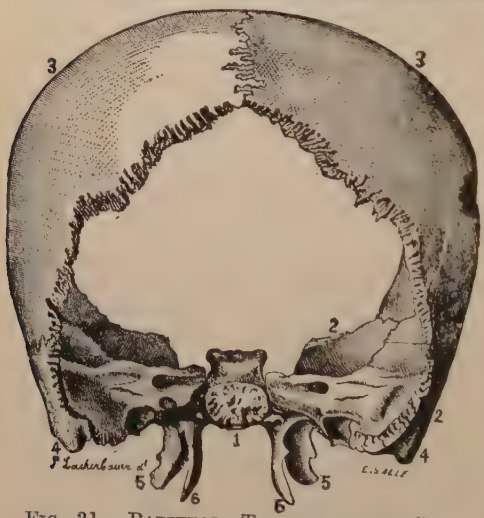


FIG. 31.—PARIETAL, TEMPORAL, AND SPHENOID BONES. Posterior aspect. 1, body of sphenoid bone; 2, 2, greater wings of sphenoid bone; 3, 3, parietal bones; 4, 4, mastoid process of temporal bones; 5, 5, external pterygoid plate; 6, 6, internal pterygoid plate. (Gould's Dictionary.)

The skull as a whole.—The cranium is a firm case or covering for the brain. Four[4] of the eight bones which form this bony covering

[4] The occipital, 2 parietal and the frontal.

are flat bones, and consist of two layers of compact tissue, the outer one thick and tough, the inner one thinner and more brittle. The cancellated tissue lying between these two layers, or "tables of the skull," is called the *diploe*. The base of the skull is much thicker and stronger than the walls and roof; it presents a number of openings for the passage of the cranial nerves, blood-vessels, etc.

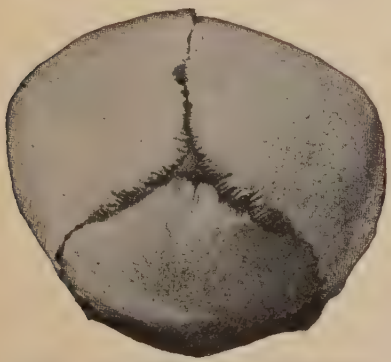


FIG. 32.—SKULL OF NEW-BORN CHILD. To show moulding. (Edgar.)

The bones of the cranium begin to develop at a very early period of fetal life. Thus, before birth the bones at the top and sides of the skull are separated from each other by membranous tissue in which bone is not yet formed, and being then imperfectly ossified, they are readily *moulded*, and overlap one another more or less during parturition.

The fontanels.—The spaces at the angles of the bone occupied by the membranous tissue are termed the fontanels, so named from the pulsations of the brain, which can be seen in some of them and which the early anatomists likened to the rise and fall of water in a fountain. There are six of these fontanels.

The *anterior fontanel* is the largest, and is a lozenge-shaped space between the angles of the two parietal bones and the two segments of the frontal bone. It remains open until the second year, and occasionally persists throughout life. (See Fig. 60.)

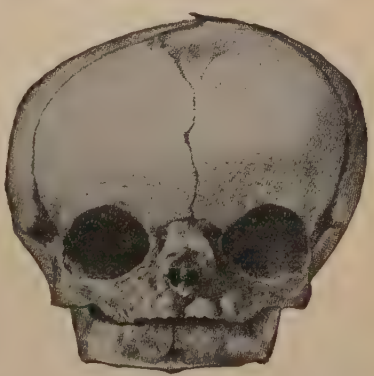


FIG. 33.—SKULL OF NEW-BORN CHILD. To show moulding. (Edgar.)

The *posterior fontanel* is much smaller in size, and is a triangular space between the occipital and two parietal bones. This is closed by an extension of the ossifying process a few months after birth. (See Fig. 61.)

The other four fontanels, two on each side of the skull, are placed at the inferior angles of the parietal bones; they are unimportant.

Sinuses of the head.—Four sinuses communicate with each nasal cavity: the frontal and the ethmoidal which open into the nasal cavity, the sphenoidal which opens into the naso-pharynx, and the maxillary or antrum of Highmore which opens on the lateral walls of the nasal passages. The mucous membrane which lines the nose also lines all of these sinuses, and inflammation of this membrane may extend into any of them and cause *sinusitis*. (See Fig. 119.)

BONES OF THE FACE

Nasal	2	14
Vomer	1	
Inferior nasal concha (Inferior turbinated)	2	
Lacrimal	2	
Zygomatic (malar)	2	
Palatine (palate)	2	
Maxilla (upper jaw)	2	
Mandible (lower jaw)	1	

Nasal bones.—They are two small oblong bones placed side by side at the middle and upper part of the face, forming by their junction the bridge of the nose. (See Figs. 25 and 34.)

Vomer.—It is a single bone placed at the lower and back part of the nasal cavity, and forms part of the central septum of the nasal cavity. It is thin, and shaped somewhat like a plowshare, but varies in different individuals, being frequently bent to one or the other side, thus making the nasal chambers of unequal size.

Inferior nasal conchæ (turbinated bones).—They are situated in the nostril, on the outer wall of each side. Each consists of a

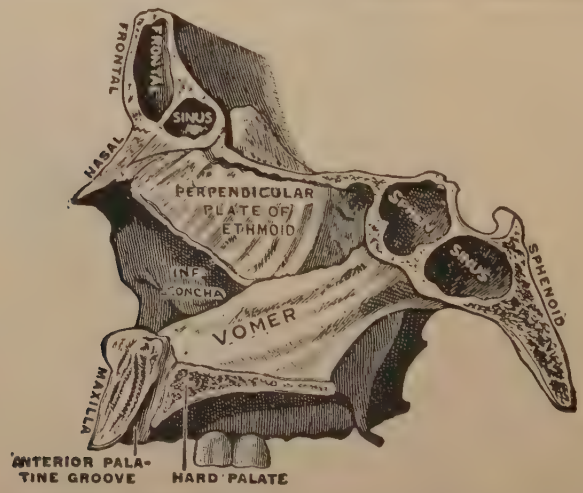


FIG. 34.—SAGITTAL SECTION OF FACE, A LITTLE TO THE LEFT OF THE MIDDLE LINE, SHOWING THE VOMER AND ITS RELATIONS. (Gerrish.)

layer of thin, cancellous bone, curled upon itself like a scroll. They are below the superior and middle conchæ of the ethmoid bone. Abnormal conditions of these bones and the membranes covering them cause some of the more common nasal diseases. (See Fig. 179.)

FIG. 35.—LACRIMAL BONE.

Lacrimal bones.—Are the smallest and most fragile bones of the face. They are situated at the front part of the inner wall of the orbit, and resemble a finger-nail in form, thinness, and size somewhat. They are named lacrimal because they contain part of the canal through which the tear duct runs.

Zygomatic, or malar bone.—Forms the prominence of the cheek and part of the outer wall and floor of the orbit. (See Figs. 25 and 26.) A prominent spine of bone projects backward from the body of the zygomatic and articulates by its free extremity with the corresponding spine projecting forward from the temporal bone, thus making the two members of the true arch known as the zygomatic arch. (See Fig. 29.)

Palatine bones.—They are shaped like an "L" and consist of a horizontal, a vertical part, and three processes, *viz.*—the pyramidal, orbital and sphenoidal processes. (See Fig. 36.) They help to form (1) the back part of the roof of the mouth; (2) part of the floor and outer wall of the nasal cavities; (3) a very small portion of the floor of the orbit.

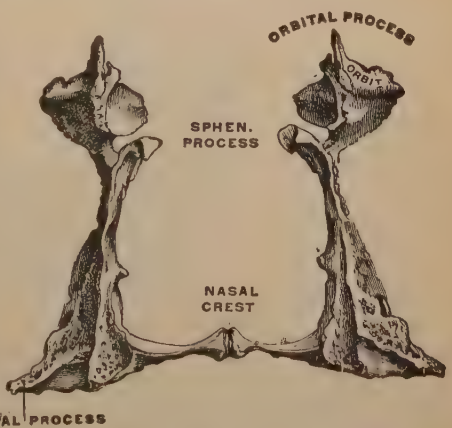


FIG. 36.—THE TWO PALATINE BONES IN THEIR NATURAL POSITION. Dorsal view. (Gerrish.)

Maxillæ, or upper jawbones, also known as superior maxillary.—The maxillæ are two in number right and left. Before birth these bones usually unite to form one bone. When they fail to do so we have the condition known as *cleft palate*. Each bone assists in forming (1) part of the floor of the orbit, (2) the floor and outer wall of the nasal cavities, (3) the greater part of the roof of the mouth.

That part of the bone which contains the teeth is called the alveolar process, and is excavated into cavities, varying in depth and size according to the size of the teeth they contain. The body of the bone is hollowed out into a large cavity known as the *antrum of Highmore*. Abnormal conditions of either the nose or teeth may cause an infection of these antrums.

FIG. 37.—THE RIGHT MAXILLA. Outer surface. (Gerrish.)

Mandible, or lower jaw-bone, also known as inferior maxillary.—It is the largest and strongest bone of the face and consists of a curved horizontal portion the body, and two perpendicular portions the rami. At birth, it consists of two lateral halves, which join at the symphysis in front and form one bone usually during the first or second year. It serves for the reception of the lower teeth, and undergoes several changes in shape during life, owing mainly (1) to the first and second dentition, (2) to the loss of teeth in the aged, and (3) the subsequent absorption of that part of the bone which contained them. It articulates, by its condyles, with the sockets in the temporal bones, which allows for free movement in mastication.

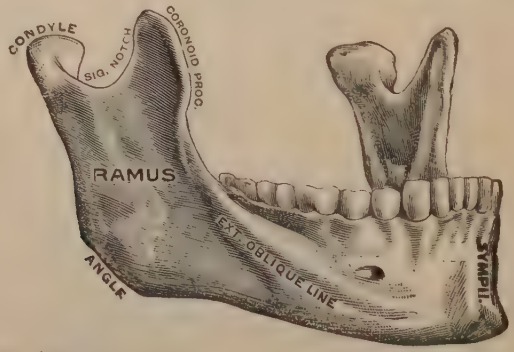


FIG. 38.—THE MANDIBLE. Viewed from the right and a little in front. (Gerrish.)

Hyoid bone (os hyoideum).—Is an isolated U-shaped bone lying in front of the throat, just above the laryngeal prominence

(Adam's apple). It supports the tongue, and gives attachment to some of its numerous muscles

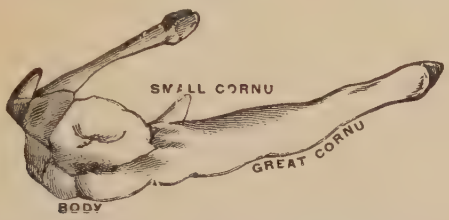


FIG. 39.—THE HYOID BONE. Viewed from the left and in front. (Gerrish.)

TRUNK

The bones which enter into the formation of the **trunk** consist of the **vertebræ, sternum,** and **ribs.**

The vertebral column as a whole.—It is formed of a series of bones called vertebræ, and in a man of average height is about twenty-eight inches long. In youth the vertebræ are thirty-three in number, and according to the position they occupy are named:—

Cervical, in the neck	7	True vertebræ.
Thoracic or dorsal in the thorax	12	
Lumbar, in the loins	5	
Sacral, in the pelvis	5	False vertebræ.
Coccygeal, in the pelvis	4	

The vertebræ in the three upper portions of the spine are separate and movable throughout the whole of life, and are known as *true* vertebræ. Those found in the sacral and coccygeal regions are, in the adult, firmly united, so as to form two bones, five entering into the upper bone, or sacrum, and four into the terminal bone of the spine, or coccyx. They are known as *false* vertebræ, and on account of their union the number of vertebræ in the adult is twenty-six.

The vertebræ.—Each vertebra consists of two essential parts, a ventral solid portion or body, and a dorsal portion or arch. Each arch has seven processes: four articular, two to connect with bone above, two to connect with bone below; two transverse, one at each side, and one spinous process, projecting backward.

Cervical vertebræ.—In the cervical region of the vertebral column the bodies of the vertebræ are smaller than in the thoracic, but the arches are larger. The spinous processes are short, and

are often cleft in two, or bifid. The transverse processes are pierced by a foramen for the passage of blood-vessels and nerves.

The first and second cervical vertebræ differ considerably from the rest. The first, or *atlas*, so named from supporting the head, has practically no body, and may be described as a bony ring divided into two sections by a transverse ligament. The dorsal section of this ring contains the spinal cord, and the ventral or front section contains the bony projection which arises from the

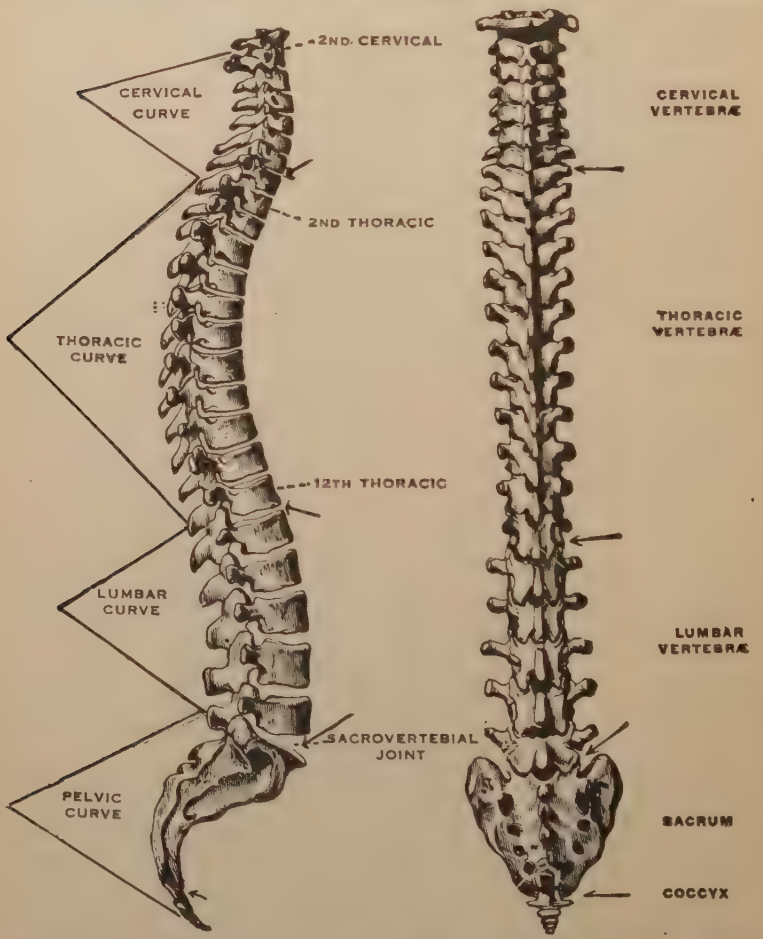


FIG. 40.—THE VERTEBRAL COLUMN. Right lateral view showing curves and dorsal view. The *cervical* curve extends from the odontoid process to the second thoracic vertebra; the *thoracic* curve extends from the second to the twelfth thoracic vertebra; the *lumbar* curve extends from the twelfth thoracic to the sacro-vertebral angle; the *pelvic* curve extends from the sacro-vertebral joint to the tip of the coccyx. (Modified from Gerrish.)

upper surface of the body of the second cervical vertebra, the epistropheus (*axis*). This bony projection, called the *odontoid* process, forms a pivot, and around this pivot the atlas rotates when the head is turned from side to side, carrying the skull, to which it is firmly articulated, with it.

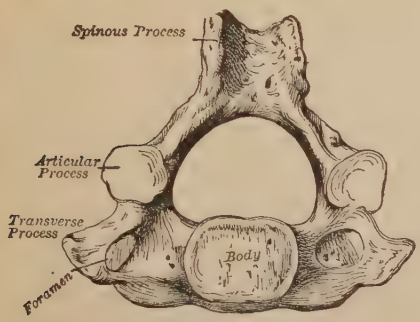


FIG. 41.—A CERVICAL VERTEBRA.

Thoracic or dorsal vertebræ.—The bodies of the thoracic vertebræ are larger and stronger than those of the cervical; and have a facet or demi-facet for articulation with the vertebral end of a rib.

Lumbar vertebræ.—The bodies of the lumbar vertebræ are the largest and heaviest in the whole spine.

Structure of vertebral column.—The bodies of the vertebræ

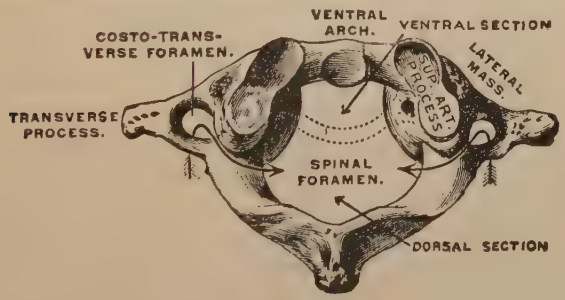


FIG. 42.—THE ATLAS. Viewed from above. (Gerrish.)

which are piled one upon another, form a strong flexible column for the support of the cranium and trunk, provide articular surfaces for the attachment of the ribs, and the arches form a hollow cylinder behind for the protection of the spinal cord. Viewed from the side, it presents four curves which are alternately convex and concave. The two concave ones, named thoracic and pelvic, are called primary curves

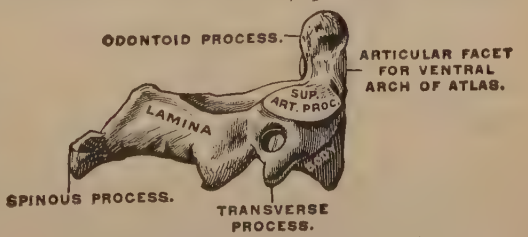


FIG. 43.—THE EPISTROPHEUS (AXIS). Its right side. (Gerrish.)

because they exist in fetal life and are designed for the accommodation of viscera. The two convex ones, named cervical and lumbar, are called secondary or compensatory curves because they are developed after birth, the former when the child is able to hold up its head and sit upright, the latter when the child begins to walk.

The different vertebræ are connected (1) by means of the articular processes, (2) by discs of intervertebral fibrocartilage placed between the vertebral bodies, (3) by strong ligaments, called respectively *anterior* and *posterior longitudinal ligaments*, which extend from the axis to the sacrum on the anterior and posterior surfaces of the bodies. (4) by broad thin ligaments called the *ligamenta flava* which connect the laminæ, and (5) by the supraspinal ligament which connects the spinous processes behind and extends from the seventh cervical vertebra to the sacrum. It is continued upward as the *ligamentum nuchæ* which extends from the protuberance of the occiput to the spinous processes of the seven cervical vertebræ. In some of the lower animals the ligamentum nuchæ serves to sustain the weight of the head, but in man it is rudimentary. (See Fig. 74.) The spinal curves confer a considerable amount of springiness and strength upon the spinal column, which would be lacking were it straight, and the elasticity is further increased by the ligamenta flava, and the discs of fibrocartilage. These discs or pads also mitigate the effects of concussion arising from falls or blows. The vertebral column is freely movable, being capable of bending forward freely, backward and from side to side less freely.[5] In the cervical and thoracic regions a limited amount of rotation is possible.

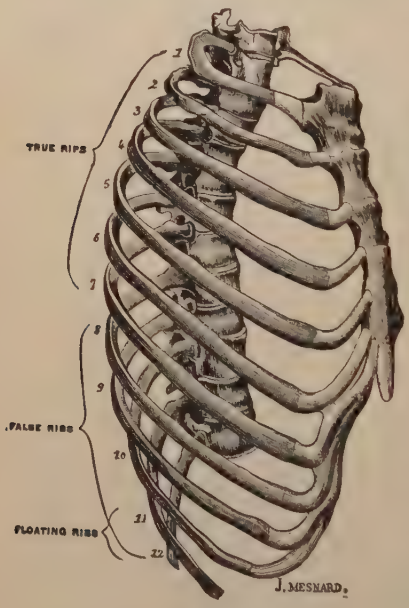


Fig. 44.—Thorax.

Abnormal conditions.—As a result of injury or disease the normal curves may become exaggerated and are then spoken of

[5] Certain exercises increase the flexibility of the spine to a marked degree.

as *curvatures*. If the thoracic curve is exaggerated it is called *kyphosis* or humpback; if the exaggeration is in the lumbar region it is called *lordosis* or hollow back. If the curvature is lateral, *i.e.* toward one side, it is called *scoliosis*. Lateral curvature is usually to the right side, because even in healthy people there is often a slight curve toward the right in the thoracic region.

It occasionally happens that the arch of one of the vertebræ does not develop properly, and as a result the membranes and fluid of the spinal cord will protrude, forming a tumor upon the child's back. This condition is called *spina bifida*, and most often occurs in the lumbar region.

Sacrum (os sacrum).—The sacrum is formed by the union of the five sacral vertebræ. It is a large triangular bone situated like a wedge between the coxal bones, and is curved upon itself in such a way as to give increased capacity to the pelvic cavity.

Coccyx (os coccygis).—The coccyx is usually formed of four small segments of bone, and is the most rudimentary part of the vertebral column.

THORAX

The thorax is formed by the sternum and costal cartilages in front, the twelve ribs on each side, and the bodies of the twelve thoracic vertebræ behind. It supports the bones of the shoulder girdle and upper extremities; contains and protects the principal organs of respiration and circulation. This bony framework encloses the thoracic cavity or chest, which is coneshaped, being small above and large below. In infancy the width from shoulder to shoulder (transverse diameter); and the depth from the sternum to the back-bone (ventral-dorsal diameter) are about equal, and thus the chest is rounded, but as growth progresses, the width increases out of proportion to the depth so that the chest gradually becomes of a somewhat oval form, and, in the adult, the width is about one-fourth greater than its depth.

Sternum, or breast bone.—It is a flat, narrow bone about six inches long, situated in the median line in the front of the chest, and may be likened to a short, flat sword. It develops as three parts. The upper part is termed the handle, or manubrium; the middle and largest piece is termed the body, or gladiolus; the inferior portion is termed the ensiform, or the xiphoid process. On both sides of the upper and middle pieces are notches for the reception of the sternal ends of the upper seven costal cartilages. The ensiform or xiphoid process has no ribs attached to it, but

affords attachment for some of the abdominal muscles. The segments of the sternum develop from several centers of ossification, and do not become completely ossified to form one bone until twenty-five, thirty or sometimes forty years of age. Consequently it is subject to the effects of posture, clothing and nutrition.

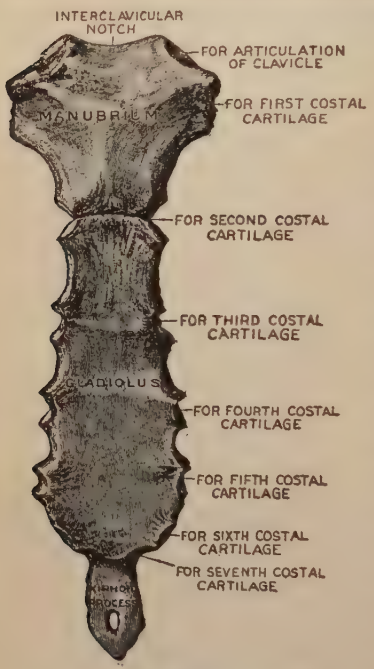


FIG. 45.—THE STERNUM. Ventral aspect. (Gerrish.)

Ribs (costæ).—The ribs, twenty-four in number, are situated twelve on each side of the thoracic cavity. They are all connected with the thoracic vertebræ at the back, by strong ligaments and the first seven pairs are connected with the sternum in front through the intervention of the costal cartilages. These first seven pairs are called, from their attachment, the *true ribs*. The remaining five pairs are termed *false ribs*. Of these, the upper three, eighth, ninth, and tenth, are attached in front to the costal cartilages of the next rib above. The two lowest being unattached in front, are termed *floating ribs*.

The convexity of the ribs is turned outward so as to give roundness to the sides of the chest and increase the size of its cavity; each rib slopes downward from its vertebral attachment, so that its sternal end is considerably lower than its dorsal, and the lower border is grooved for the accommodation of the intercostal nerves and blood-vessels. The spaces left between the ribs are called the intercostal spaces. The skull and trunk (spinal column and thorax) constitutes the *axial skeleton*.

BONES OF THE UPPER EXTREMITIES

Shoulder Girdle	Clavicle, clavicula, or collar bone	2	64
	Scapula, shoulder blade	2	
Humerus, upper arm		2	
Ulna, large bone of forearm		2	
Radius, small bone of forearm		2	
Carpus, wrist		16	
Metacarpus, body of hand		10	
Phalanges, 2 in thumb, 3 in each finger		28	

Clavicle, or collar bone.—It is a long bone, placed horizontally above the thorax. It articulates with the sternum by its inner extremity, which is called the sternal extremity. Its outer or acromial extremity articulates with the scapula. In the female,

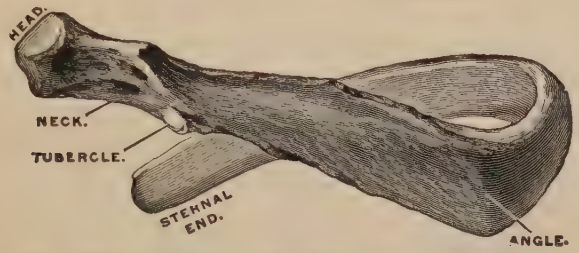


FIG. 46.—THE EIGHTH RIB OF THE RIGHT SIDE. Viewed from behind. (Gerrish.)

the clavicle is generally less curved, smoother, shorter, and more slender than in the male. In those persons who perform considerable manual labor, which brings into constant action the muscles connected with this bone, it acquires considerable bulk.

Scapula, or shoulder blade.—It is a large, flat bone, triangular in shape, placed between the second and eighth ribs on the back part of the thorax. It is unevenly divided on its dorsal surface by a very prominent ridge, the spine of the scapula, which terminates in a large triangular projection called the *acromion process* which articulates with the clavicle. Below the acromion process, at the head of the shoulder blade, is a shallow socket, the *glenoid cavity*, which receives the head of the humerus. These four bones (clavicles and scapulæ) by which the upper limbs are

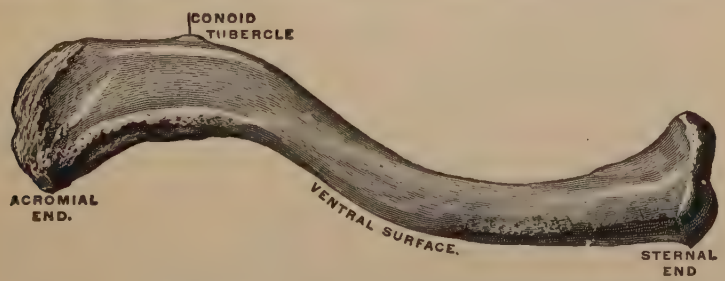


FIG. 47.—THE RIGHT CLAVICLE. Upper surface. (Gerrish.)

attached to the trunk constitute the *shoulder girdle*. It is completed in front by the upper end of the sternum, but is incomplete behind as the scapulæ are connected to the trunk by muscles only.

Humerus, or upper arm bone.—The humerus is the longest

bone of the upper limb. The upper extremity of the bone consists of a rounded head joined to the shaft by a constricted neck, and of two eminences called the larger and smaller tubercles. The head articulates with the glenoid cavity of the scapula. The constricted neck above the tubercles is called the anatomical neck, and that below the tubercles, the surgical neck, because it is so often fractured. The lower extremity of the bone is flattened from before backward into a broad articular surface called the trochlea which is divided by a slight ridge so that it ends in

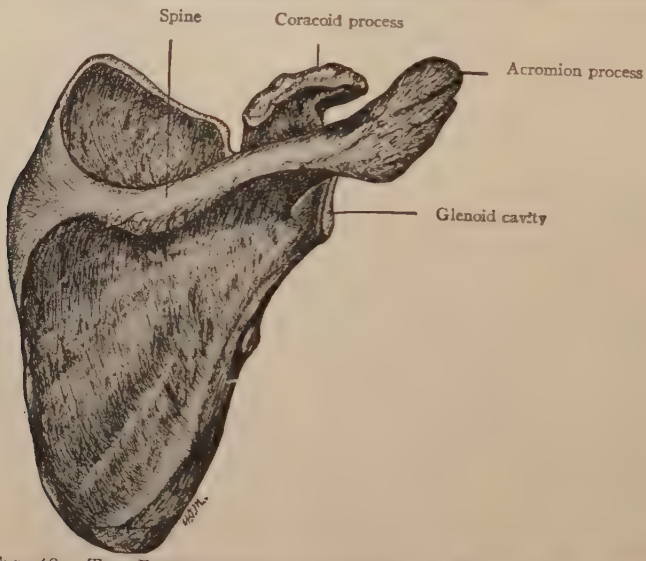


FIG. 48.—THE RIGHT SCAPULA, OR SHOULDER BLADE. (MORROW.)

two condyles by means of which it articulates with the radius and ulna.

Ulna, or elbow bone.—It is the large bone of the forearm and is placed at the inner side (little finger side) parallel with the radius. Its upper extremity presents for examination two large curved processes and two concave cavities; the larger process forms the head of the elbow, and is called the olecranon process. The smaller process on the front surface is termed the coronoid, and the trochlea of the humerus fits into the cavity—the great sigmoid cavity—between these two processes. The lesser sigmoid cavity is on the outer side of the coronoid, and receives the head of the radius. The lower extremity of the ulna is of small size and ends in two prominences; the outer one, called the head, articulates with the radius; the inner one, named the styloid

process, serves for the attachment of ligaments from the wrist; but the ulna is excluded from the wrist by a piece of fibrocartilage.

Radius.—It is the small bone of the forearm and is situated on the outer side. The upper end is small and rounded, with a shallow depression on its upper surface for articulation with the humerus, and a prominent ridge about it, like the head of a nail, by means of which it rotates within the lesser sigmoid cavity of

FIG. 49.—THE RIGHT HUMERUS, OR ARM BONE. Anterior view. (Morrow.)

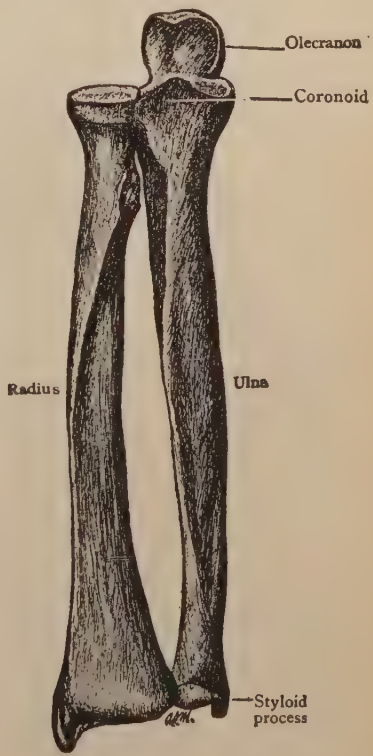


FIG. 50.—THE BONES OF THE RIGHT FOREARM. Anterior view. (Morrow.)

the ulna. The lower end of the radius is large, and forms the chief part of the wrist. It is often fractured, and such fracture is termed Colles' fracture.

Carpus, or wrist.—The wrist joint is composed of eight small bones, (ossa carpi) united by ligaments; they are arranged in two rows, and are closely welded together, yet by the arrangement of their ligaments allow of a certain amount of motion. They

afford origin by their palmar surface to most of the short muscles of the thumb and little finger, and are named as follows:—

1st row.		2nd row.		
1. Navicular (scaphoid)	1	5. Greater multangular (trapezium	1	8
2. Lunate (semilunar)	1	6. Lesser multangular (trapezoid)	1	
3. Triangular (cuneiform)	1	7. Capitate (os magnum)	1	
4. Pisiform	1	8. Hamate (unciform)	1	

Metacarpus, or body of hand.—Each metacarpus is formed by five bones (ossa metacarpalia). The bones are curved longitudinally, being convex behind, and concave in front. They articulate at their bases with the second row of carpal bones and with each other. The heads of the bones articulate with the bases of the first row of the phalanges.

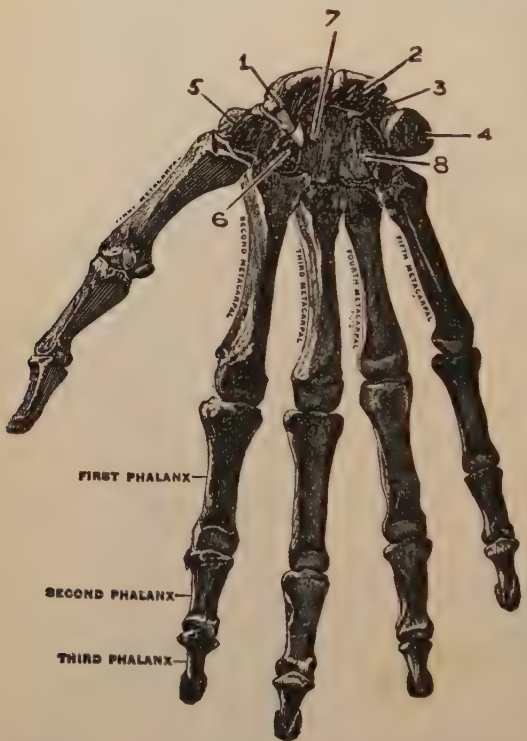


FIG. 51.—THE BONES OF THE RIGHT HAND. Palmar aspect. For names of carpal bones, compare numbers on bones, to numbers in list above.

Phalanges, or digits.—They are the bones of the fingers, and are fourteen in number in each hand, three for each finger and two for the thumb. The first row articulates with the metacarpal bones and the second row of phalanges; the second row, with the first and third; and the third, with the second row.

BONES OF THE LOWER EXTREMITIES

Hip bones, ossa coxæ or ossa innominata	2	62
Femur, thigh bone	2	
Patella, knee-cap	2	
Tibia, shin bone, 2 / Fibula, small bone of calf, 2 } leg	4	
Tarsus, heel and upper instep	14	
Metatarsus, sole and lower instep	10	
Phalanges, 2 in great toe, 3 in others	28	

The bones of the lower extremities correspond to a great extent with those of the upper extremities, and bear a rough resemblance to them, but their function is different. The lower limbs support the body in the erect position and are therefore more solidly built, and their parts are less movable than the corresponding parts of the upper limbs.

Hip bone, or os coxæ.—It is a large, irregularly shaped bone which, with its fellow of the opposite side, forms the sides and front wall of the pelvic cavity. In young subjects it consists of three separate parts, and although in the adult these have become united, it is usual to describe the bone as divisible into three portions: (1) the ilium (plural *ilia*), (2) the ischium (plural *ischia*), (3) the pubis (plural *pubes*).

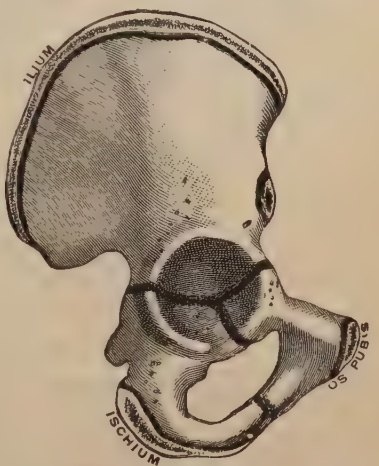


FIG. 52.—DEVELOPMENT OF THE HIP BONE. Showing the union of the three portions in the acetabulum. (Gerrish.)

The **ilium** is the upper broad and expanded portion which forms the prominence of the hip. The **ischium** is the lower and strongest portion of the bone, while the **pubis** is that portion which helps to form the front of the pelvis. Where these three portions of the bone meet and finally ankylose, is a deep socket, called the *acetabulum*, into which the head of the femur fits. Other points of special interest to note in the hip bones are:—

(1) The processes formed by the projection of the crest of the ilium in front, which are called the anterior superior iliac spine and the anterior inferior iliac spine. The former is a convenient landmark in making anatomical and surgical measurements.

(2) The largest foramen in the skeleton, known as the *obturator (thyroid) foramen* situated between the ischium and pubis.

(3) The *symphysis pubis*, or pubic articulation, which also serves for a convenient landmark in making measurements.

The pelvis.—The pelvis, so called from its resemblance to a basin, is stronger and more massively constructed than either the cranial or the thoracic cavity. It is composed of four bones, the two hip bones forming the sides and front, the sacrum and coccyx completing it behind. It is divided by a narrowed bony ring into

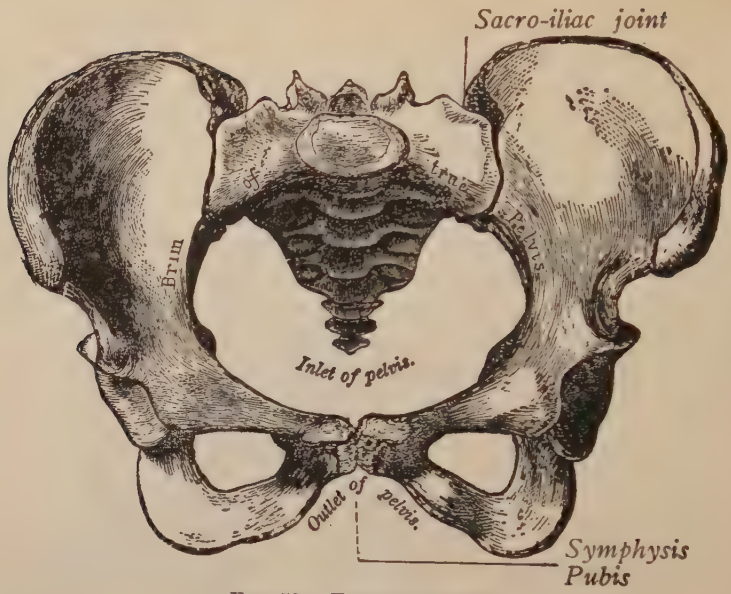


FIG. 53.—FEMALE PELVIS.

the *large* false, and *small* true pelvis. The narrowed bony ring which is the dividing line is spoken of as the *brim of the pelvis*, the *ilio-pectineal line*, and the *strait*. The large pelvis is all that

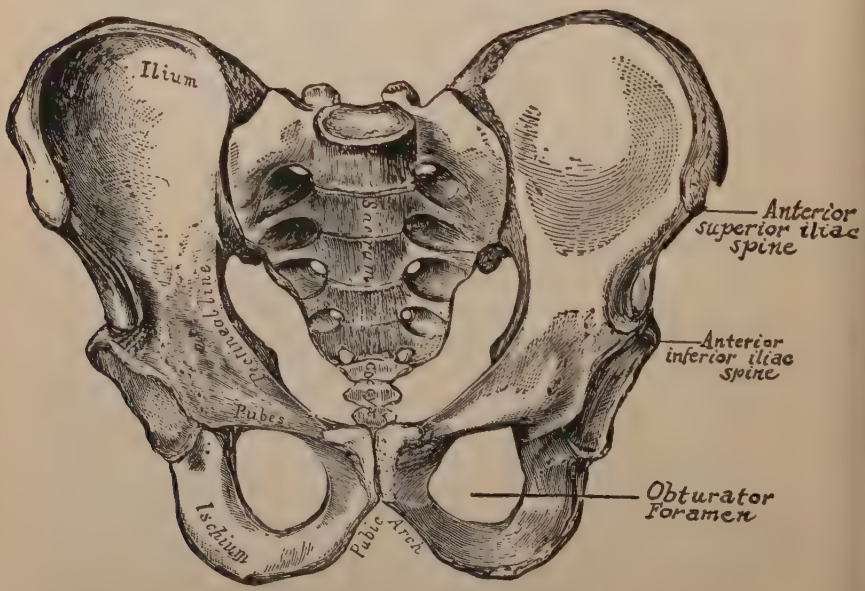


FIG. 54.—MALE PELVIS.

expanded portion of the pelvis situated above the brim; it forms an incomplete or *false* basin. The small pelvis is all that portion situated below the brim. Its cavity is a little wider in every direction than the brim itself, while the large pelvis is a great deal wider. The small bony pelvis is a basin with incomplete walls of bone, the bottom of which is composed of the softer tissues, muscles, and ligaments. The opening of the small pelvis, *i.e.*, the space just above the brim, is called the *inlet*, and the opening below is called the *inferior* strait, or *outlet*.

The female pelvis differs from that of the male in those particulars which render it better adapted to pregnancy and parturition. It is more shallow than the male pelvis, but wider in every direction. The inlet and outlet are larger, the bones are lighter and smoother, and the coccyx is more movable. As can be seen by looking at Fig. 53 and Fig. 54, a distinctive anatomical difference is that the sub-pubic angle in a male is less than a right angle, and in the female it is greater than a right angle. The hip bones constitute the *pelvic girdle*. In front they articulate with each other, and behind they articulate with the sacrum, which fills in the gap and forms a more massive and complete ring than the shoulder girdle.

FIG. 55.—THE RIGHT FEMUR, OR THIGH BONE. Anterior view. (Morrow.)

Femur, or thigh bone.—It is the longest and strongest bone in the skeleton. The upper extremity of the femur, like that of the humerus, consists of a rounded head joined to the shaft by a

constricted neck, and of two eminences, called the greater and lesser *trochanters*. The head articulates with the cavity in the hip bone, called the acetabulum. The lower extremity of the femur is larger than the upper, is flattened from before backwards, and divided into two large eminences or *condyles* by an intervening notch. It articulates with the tibia and the patella, or knee-cap. In the erect position it is not vertical, being separated from its fellow by a considerable interval, which corresponds to the entire breadth of the pelvis, but the bone inclines gradually downward and inward, so as to approach its fellow towards its lower part, in order to bring the knee-joint near the line of gravity of the body. The degree of inclination varies in different persons, and is greater in the female than the male, on account of the greater breadth of the pelvis.

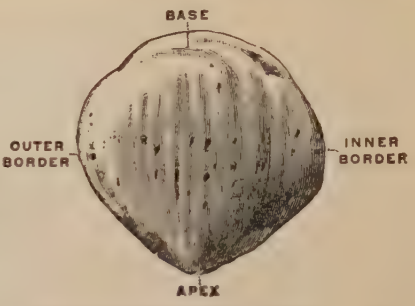


FIG. 56.—THE RIGHT PATELLA. Ventral surface. (Gerrish.)

FIG. 57.—THE BONES OF THE RIGHT LEG. (Morrow.)

Patella, or knee-cap.—It is the largest sesamoid bone in the body. It is small, flat, triangular in shape, and placed in front of the knee-joint, which it serves to protect. (See Fig. 23.) It articulates with the two condyles of the femur, and is separated from the skin by a bursa.[6]

Tibia, or shin bone.—It is situated at the front and inner side of the leg. The upper extremity is large, and expanded into two lateral eminences with concave surfaces, which receive the condyles

[6] See page 177.

of the femur. The lower extremity is much smaller than the upper; it is prolonged downward on its inner side into a strong process, the inner, or *medial, malleolus.* It articulates with the fibula and the talus. (In the male, its direction is vertical and parallel with the bone of the opposite side; but in the female it has a slightly oblique direction outward, to compensate for the oblique direction of the femur inward.)

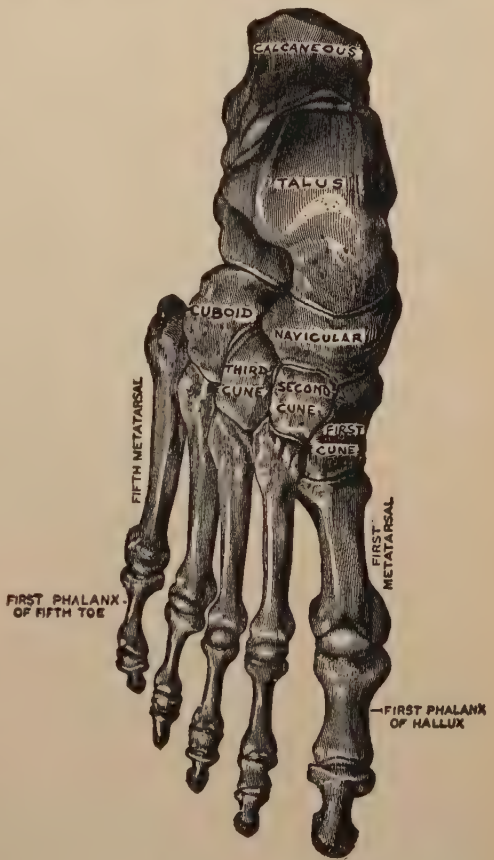


FIG. 58.—THE BONES OF THE RIGHT FOOT. Viewed from above. (Gerrish.)

Fibula, or small bone of calf.—It is situated at the outer side of the leg. It is the smaller of the two bones, and, in proportion to its length, the most slender of all the long bones; it is placed nearly parallel with the tibia. The upper extremity consists of an irregular quadrate head by means of which it articulates with the tibia. The lower extremity is prolonged downward into a pointed process, the external, or *lateral, malleolus,* which lies just beneath the skin. It articulates with the tibia and the talus. A fracture of the lower end of the fibula with injury of the lower tibial articulation is called a Pott's fracture.

Tarsus.—The tarsus is composed of seven small bones united by ligaments, but the tarsal bones differ from the carpal in being larger and more irregularly shaped. The largest and strongest of the tarsal bones is called the **calcaneus** or **heel bone**; it serves

to transmit the weight of the body to the ground, and forms a strong lever for the muscles of the calf of the leg.

Metatarsus, or sole and instep of foot.—The metatarsus is formed by five bones which closely resemble the metacarpal bones of the hand. Each bone articulates with the tarsal bones by one extremity, and by the other with the first row of phalanges. The tarsal and metatarsal bones are so arranged that they form two distinct arches, one running from the heel to the toes on the inner (medial) side of the foot is called the *longitudinal arch*, and the other across the foot in the metatarsal region is called the *transverse arch*.

Phalanges, or digits.—Both in number and general arrangement they resemble those in the hand, there being two in the great toe and three in each of the other toes.

SUMMARY

Bones

- Function
  1. Organs of support.
  2. Instruments of locomotion.
  3. Framework of hard material.
  4. Afford attachment to soft parts.
  5. Shelter delicate structures.
  6. Shape to whole body.
- Classification
  1. Long.
  2. Short.
  3. Flat.
  4. Irregular.

TABLE OF THE BONES

HEAD

Cranium		Face	
Occipital	1	Nasal	2
Parietal	2	Vomer	1
Frontal	1	Inferior nasal concha (Inferior turbinated)	2
Temporal	2	Lacrimal	2
Sphenoid	1	Zygomatic (Malar)	2
Ethmoid	1	Palatine (Palate)	2
	8	Maxilla	2
		Mandible	1
			14

Ear	Malleus	2
	Incus	2
	Stapes	2
		6
Hyoid bone in the neck		1

TRUNK

		Child	Adult
Vertebræ	Cervical	7	7
	Thoracic	12	12
	Lumbar	5	5
	Sacral	5	1
	Coccygeal	4 = 33	1 = 26
Ribs			24
Sternum			1
			51

Upper Extremity

Clavicle	1
Scapula	1
Humerus	1
Ulna	1
Radius	1
Carpus	
Navicular (Scaphoid)	1
Lunate (Semilunar)	1
Triangular (Cuneiform)	1
Pisiform	1
Greater Multangular (Trapezium)	1
Lesser multangular (Trapezoid)	1
Capitate (Os magnum)	1
Hamate (Unciform)	1
Metacarpus	5
Phalanges	14
	32

$32 \times 2 = 64$

Lower Extremity

Hip bone (os coxæ)	1
Femur	1
Patella	1
Tibia	1
Fibula	1
Tarsus	
Calcaneus (Calcaneum)	1
Talus (Astragalus)	1
Cuboid	1
Navicular (Scaphoid)	1
Third cuneiform (External cuneiform)	1
Second cuneiform (Middle cuneiform)	1
First cuneiform (Internal cuneiform)	1
Metatarsus	5
Phalanges	14
	31

$31 \times 2 = 62$

CHAPTER V

JOINTS OR ARTICULATIONS

The various bones of which the skeleton consists are connected at different parts of their surfaces, and such connections are called joints or articulations.

Classification.—Joints are classified according to the amount of movement of which they are capable.

1. Immovable joints or synarthroses.
2. Slightly movable joints, or amphiarthroses.
3. Freely movable joints, or diarthroses.

In all instances some softer substance is placed between the bones, uniting them or clothing the opposed surfaces; but the manner in which the several pieces of the skeleton are thus connected varies to a great degree.

Immovable joints, or synarthroses.—The bones are connected by fibrous tissue or cartilage. There are four varieties. These are listed in the summary. The bones of the cranium and the facial bones (with the exception of the lower jaw) have their adjacent surfaces applied in close contact, with only a thin layer of fibrous tissue placed between their margins.

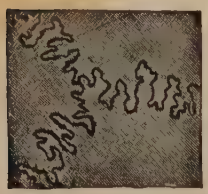


FIG. 59.—A TOOTHED, OR DENTATED, SUTURE.

In most of the cranial bones this union occurs by means of series of processes and indentations interlocked together, which form jagged lines of union known as **sutures.**

The three most important sutures are:—

(1) *Coronal.*—The line of union between the frontal and parietal bones.

(2) *Lambdoidal.*—The line of union between the parietal and occipital bones.

(3) *Sagittal suture.*—This begins at the base of the nose, extends along the middle line on the top of the crown, separates

the frontal bone into two parts,[1] the parietal bones from each other, and ends at the posterior fontanel.

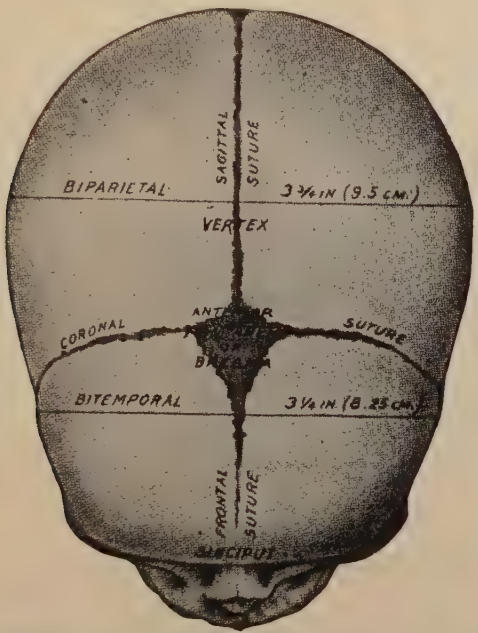


FIG. 60.—DIAMETERS AND LANDMARKS OF THE FETAL SKULL. Upper surface. (Edgar.)

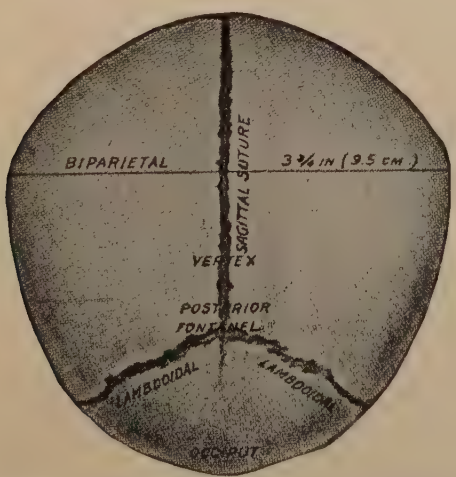


FIG. 61.—DIAMETERS AND LANDMARKS OF THE FETAL SKULL. Posterior surface. (Edgar.)

[1] That portion of the sagittal suture which separates the frontal bone into two parts is often called the *frontal suture*. (See Fig. 60.)

Slightly movable joints, or amphiarthroses.—These terms are applied to joints that permit of slight movement and include two varieties: (1) symphysis and (2) syndesmosis.

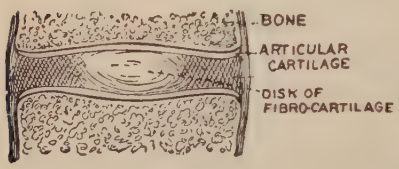


FIG. 62.—A SLIGHTLY MOVABLE JOINT.

Symphysis.—In this form of articulation the bony surfaces are joined together by broad, flattened discs of fibrocartilage, as in the articulations between the bodies of the vertebræ. These intervertebral discs being compressible and extensile, the spine can be moved to a limited extent in every direction. In the pelvis the articulations between the two pubic bones (symphysis pubis), (See Fig. 53), and between the sacrum and ilia (sacro-iliac articulation), are slightly movable. The pubic bones are united by a disc of fibrocartilage and by ligaments. In the sacro-iliac articulation the sacrum is united more closely to the ilia, the articular surfaces being covered by cartilage and held together by ligaments.

The fibrocartilage between these joints (symphysis pubis and sacro-iliac) becomes thickened and softened during pregnancy and allows of a certain limited motion which is essential to a normal parturition.

Syndesmosis.—An articulation by means of an interosseous ligament, as in the lower tibio-fibular articulation, is called syndesmosis.

Freely movable joints, or diarthroses.—This division includes the greater number of joints in the body. Each articular end of the bone is covered with hyaline cartilage and connected by means of ligaments which form more or less perfect capsules The capsules are lined by synovial membrane. (See Fig. 63.)

The varieties of joints in this class have been determined by the kind of motion permitted in each. They are as follows:—

(1) *Gliding joint.*—The articular surfaces are nearly flat, or one may be slightly concave, the other slightly convex. They admit of only gliding movement, as in the joints between the articular processes of the vertebræ.

(2) *Hinge joint.*—The articular surfaces are of such shape as to permit of movement to and fro in one plane only, like a door on its hinges. These movements are called flexion and extension,

and may be seen in the articulation between the humerus and ulna, in the ankle joint, and in the articulations of the phalanges.

(3) *Ball-and-socket joint.*—In this form of joint a more or less rounded head is received into a cup-like cavity, as the head of the femur into the acetabulum, and the head of the humerus into the glenoid cavity of the scapula. Movement can take place freely in any direction, but the shallower the cup, the greater the extent of motion. The shoulder joint is the most freely movable joint in the body.

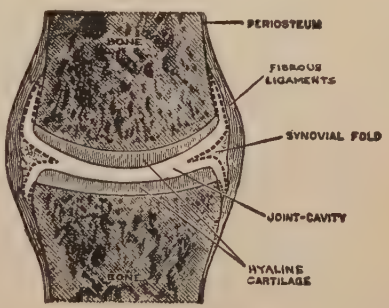


FIG. 63.—A COMPLETE JOINT. The synovial membrane is represented by dotted lines.

(4) *Pivot joint.* — In this form, one bone rotates around another which remains stationary, as in the articulation of the atlas with the epistropheus, (axis) and in the articulation of the ulna and radius. In the articulation of the ulna and radius, the ulna remains stationary, and the radius rotates freely around its upper end. The hand is attached to the lower end of the radius, and the radius, in rotating, carries the hand with it; thus, the palm of the hand is alternately turned forward and backward. When the palm is turned forward, or upward, the attitude is called supination; when backward, or downward, pronation.

(5) *Condyloid joint.*—When an oval-shaped head, or condyle, of a bone is received into an elliptical cavity, it is said to form a condyloid joint. An example of this kind of joint is found in the wrist joint.

(6) *Saddle joint.*—In this joint the articular surface of each bone is concave in one direction, and convex in another, at right angles to the former. The metacarpal bone of the thumb is articulated with the greater multangular bone of the carpus by a saddle joint. Both the condyloid and saddle joints admit of motion in every direction except that of axial rotation.

Movement.—Bones thus connected are capable of the following different kinds of movement.

1. *Gliding movement.*—This is the simplest kind of motion

that can take place in a joint, one surface gliding or moving over another without any angular or rotatory movement.

2. *Angular movement.*— This occurs only between the long bones, and by it the angle between the two bones is either increased or diminished. It includes flexion, extension, abduction and adduction.

a. *Flexion.*—A limb is flexed, when it is bent, *e. g.*, bending the arm.

b. *Extension.*—A limb is extended, when it is straightened out, *e. g.*, straightening the arm, hence the reverse of flexion.

c. *Abduction.*—This term means drawn away from the middle line of the body, *e. g.*, bending the trunk sideways.

d. *Adduction.*—This term means brought to, or nearer the middle line of the body, *e. g.*, bringing the trunk back to the upright position.

Both abduction and adduction have a different meaning when used with reference to the fingers and toes. In the hand the imaginary line is supposed to be drawn through the middle finger; and in the foot through the second toe.

3. *Circumduction.*—Means that form of motion which takes place between the head of a bone and its articular cavity, when the bone is made to circumscribe a conical space by rotation around an imaginary axis, *e. g.*, swinging the arms or legs.

4. *Rotation.*—Means a form of movement in which a bone moves around a central axis, often an imaginary one, without undergoing any displacement from this axis, *e. g.*, rotation of the atlas on the axis.

No part of the body is capable of perfect rotation, as a wheel, for the simple reason that such motion would necessarily tear asunder all the vessels, nerves, muscles, etc., which unite it with other parts.

Sprain.—A wrenching or twisting of a joint accompanied by a stretching or tearing of the ligaments or tendons is called a sprain.

Dislocation.—If in addition to a sprain, the bone is displaced the injury is called a dislocation.

SUMMARY

Joints or Articulations—connections existing between bones.

Immovable Joint or Synarthrosis — Bones are connected by fibrous tissue or cartilage.

- *Sutures.*—Articulations by processes and indentations interlocked together.
  - *True Sutures*
    - Sutura dentata—tooth-like, *e.g.*, sutures between parietal bones.
    - Sutura serrata—saw-like, *e.g.*, sutures between two portions of frontal bone.
    - Sutura limbosa—in addition to interlocking the articular surfaces are beveled and overlap, *e.g.*, suture between parietal and frontal bones.
  - *False Sutures*
    - Sutura squamosa—scale-like, *e.g.*, sutura between the temporal and parietal bones.
    - Sutura harmonica—simple apposition of rough surfaces, *e.g.*, articulations between the maxillæ.
- *Schindylesis.*—A thin plate of bone is received in a cleft or fissure of another bone, *e.g.*, the reception of the vomer in the fissure between maxillæ, and between the palatine bones.
- *Gomphosis.*—A conical process fits into a socket, *e.g.*, roots of teeth into the alveoli of the maxillæ and mandible.
- *Synchrondrosis.*—Temporary joint. Cartilage between bones ossifies in adult life, *e.g.*, between the occipital and sphenoid.

Slightly Movable Joint or Amphiarthrosis — Bones are connected by discs of cartilage or interosseous ligaments.

1. *Symphysis.*—The bones are united by a plate or disc of fibrocartilage of considerable thickness.
2. *Syndesmosis.*—The bony surfaces are united by an interosseous ligament, as in the lower tibio-fibular articulation.

Movable Joint or Diarthrosis — 1. Hyaline cartilage covering articular ends of bones. 2. Fibrous ligament forming a capsule. 3. Synovial membrane lining fibrous capsule.

1. *Arthrodia.*—Gliding joint; articulates by surfaces which glide upon each other.
2. *Ginglymus.*—Hinge or angular joint; moves backward and forward in one plane.
3. *Enarthrosis.*—Ball-and-socket joint; articulates by a globular head in a cup-like cavity.
4. *Trochoides.*—Pivot joint; articulates by a process turning within a ring, or by a ring turning around a pivot.
5. *Condylarthrosis.*—Condyloid joint; ovoid head received into elliptical cavity.
6. *Reciprocal Reception.*—Saddle joint; articular surfaces are concavo-convex.

Movement

1. Gliding movement.
2. Angular. — Flexion. Extension. Abduction. Adduction.
3. Circumduction.
4. Rotation.

CHAPTER VI

MUSCULAR TISSUE: CLASSIFICATION; FUNCTIONALLY IMPORTANT SKELETAL MUSCLES

One of the important functions of the human body is *motion*. Under this heading is included many types of movements, *i.e.*, the ability to move from place to place, the movements of breathing, the beating of the heart, the activities of the stomach, etc. Varied as these movements seem to be they are all dependent upon the forcible contraction of muscular tissue. This tissue[1] arises from the mesoderm, forms the bulk of all the muscles which are attached to the skeleton, and which by contracting bring about changes in the form and position of nearly all parts of the body.

Muscular tissue also forms the walls of such organs as the heart, stomach and intestines. Contractions of this tissue decrease the capacity of these organs, while relaxation increases it. Consequently, muscular tissue is classed as a motor tissue, but the activities of the muscular system are dependent upon the skeletal and the nervous systems. In fact the skeletal, the muscular and the nervous systems are correlated parts, the degree of usefulness of any one of them depending on the development and proper functioning of the others.

The appearance of human muscular tissue is roughly comparable to the lean of butcher's meat. It constitutes from 40 to 50 per cent of the body weight.

Characteristics.—The characteristics that enable it to perform the function of motion are irritability (excitability), contractility, extensibility and elasticity.

Irritability or *excitability* may be defined as the power of receiving and responding to stimuli. All cells possess this property; neurons, ciliated epithelial cells, and the cells of muscular tissue in a marked degree. The response of any tissue to stimulation is to perform its special function, and in the case of muscular tissue this response takes the form of contraction

Contractility is the power which enables muscles to change their shape so as to become shorter and thicker. It is possessed

[1] The muscles of the hair, and the ciliary muscles of the eyes excepted.

to some degree by all living protoplasm, but is highly developed in muscular tissue.

Extensibility of a living muscle means that it can be stretched or extended, and *elasticity* means that it readily returns to its original form. Normally, the skeletal muscles are in a condition of slight tension, being stretched from bone to bone. This condition is of importance in two ways: (1) smoothness of movement is dependent upon it; (2) a stretched muscle will contract more quickly than one that is relaxed.

Like every other tissue muscular tissue is composed of cells and intercellular substance, with this difference, that the cells become elongated. The intercellular substance consists of a small amount of cement, which helps to hold the cells together, or to the framework of reticular tissue in which they are embedded.

CLASSIFICATION

Muscle cells are of three distinct kinds, and we therefore distinguish three varieties of muscular tissue:—

1. Striated or cross-striped.
2. Non-striated or smooth.
3. Cardiac.

Striated or cross-striped muscular tissue.—This tissue is called striated because of the horizontal striac or parallel cross-stripes which characterize its microscopic appearance. It is also called skeletal because it forms the muscles which are attached to the skeleton, and voluntary because it is nearly always under the control of the will. It is composed of muscle cells, which are long and spindle-shaped, measuring on an average one inch or more in length, and from $\frac{1}{2500}$ to $\frac{1}{250}$ of an inch (0.01 to 0.1 mm) in diameter. Under the microscope they show a cell wall called sarcolemma and numerous small nuclei. Micro-dissection show white fibrils (fibrillæ) which are closely packed together and run lengthwise through the entire cell. A small amount of fluid material called sarcoplasm surrounds the fibrillæ.

The muscle cells lie closely packed, their ends lapping over onto adjacent cells and forming bundles. Reticular tissue forms a supporting frame work for muscular tissue. It penetrates between the cells and surrounds the small bundles grouping them into larger bundles. It also surrounds the larger bundles and forms a covering for the whole muscle. This reticular tissue carries an intricate network of blood-vessels and nerves.

Every muscle cell comes into close contact with blood capillaries, and is surrounded with lymph. Every muscle cell is the seat of nerve endings.

FIG. 64.—DIAGRAM OF MUSCLE CELL WITH SARCOLEMMA ATTACHED.

Skeletal Muscles.—The muscles are separate organs, each muscle having its own sheath of connective tissue, called epimysium. They vary in size from a fraction of an inch to nearly twenty-four inches (60 cm.) and are very diverse in form. In the trunk the muscles are broad, flattened, and expanded, forming the walls of the cavities which they enclose. In the limbs they are of considerable length, forming more or less elongated straps. A typical muscle is described as consisting of a body and two extremities. The body is the red contracting part, and the extremities are the ends where they are attached.

Attachment of the Muscles to the skeleton.—Muscles are attached to the bones, cartilages, ligaments, and skin in various ways, the most common mode of attachment being by means of *tendons*. The muscle fibers converge as they approach their tendinous extremities, and gradually blend with the fibers of the tendons, the tendons in their turn inserting their fibers into the bones. Where one muscle connects with another, each muscle ends in expanded form in a flat, fibrous membrane called an *aponeurosis*. Again, in some cases, the muscles are connected with the bones, cartilages, and skin, without the intervention of tendons or aponeuroses.

Fasciæ.—As previously stated (page 26), most of the muscles are closely covered by sheets of fibrous tissue called fasciæ. These fasciæ not only envelop and bind down the muscles, but also separate them into groups. Such groups are named according to the parts of the body where they are found, *viz.:* cervical fascia, thoracic fascia, abdominal fascia, pelvic fascia, etc. Individual fascia are frequently given the names of the muscles which they envelop and bind down, *viz.:* temporal fascia, pectoral fascia, deltoid fascia, etc. It is important for the student to realize the continuity of the fibrous membranes. Tendons, ligaments, and fasciæ blend with periosteum; tendons and fasciæ serve as ligaments; tendons lose themselves in fasciæ; and tendons of some muscles serve as fasciæ for others.

Annular ligaments.—In the vicinity of the wrist and ankle, parts of the deep fascia become blended into tight transverse bands, which serve to hold the tendons close to the bones. These bands are called annular ligaments. (See Fig. 118.)

Origin and insertion.—It is customary to speak of the attachments of the opposite ends of muscles under the names of origin and insertion, the first term *origin* being usually applied to the more fixed attachment; the second term *insertion* being applied to the more movable attachment. The origin is, however, absolutely fixed in only a very small number of muscles, such as those of the face, which are attached by one end to the bone, and by the other to the movable skin.

Non-striated or smooth muscular tissue.—This tissue is called smooth because it does not exhibit cross stripes or striæ. It is called *visceral* because it constitutes a large portion of the walls of the viscera, and *involuntary* because it is usually withdrawn from the control of the will. It is composed of spindle-shaped cells containing a single large nucleus embedded in the cell substance. These cells are always much shorter than the cells of striated tissue and are held in place by a network of connective tissue which carries blood-vessels and nerves. In most parts of the body smooth muscle is arranged as a tube which forms the wall of the part concerned, *e.g.*, the intestines and blood-vessels. It usually consists of two main layers, one called the *circular*, the other the *longitudinal* layer or coat. The circular coat is the thicker.

FIG. 65.—ELONGATED CELLS OF PLAIN MUSCULAR TISSUE. (Highly magnified.)

Cardiac muscular tissue.—This variety of muscular tissue is found only in the heart substance. It is involuntary, but is striated, though not as distinctly as skeletal muscle. It is made up of irregularly shaped cells, which are grouped together in bundles and held in place by connective tissue which forms a supporting framework.

Stimuli.—This term is applied to influences which produce excitability in living matter. Any environmental change may constitute a stimulus. They may be chemical, *e.g.*, changes in food or water, or substances of a foreign character; or changes in concentration;[2] mechanical or pressure changes; thermal or

[2] See page 398.

temperature changes; electrical, and nervous, *e.g.*, impulses conveyed by nerves. In all cases the result of the stimulation of muscle cells is contraction.

Nerves.—Muscular tissue is well supplied with nerves. Certain nerves convey impulses from the central nervous system to the muscles and control their contraction. These are called motor nerves. Certain other nerves have sensory end organs in the muscles. These convey to the central nervous system the state of contraction of the muscle and hence are called sensory nerves. By means of these sets of nerves coördinated activities of groups of muscles are brought about.[3]

Varieties of muscular movements.—According to their causation we divide muscular movements into two classes: voluntary, and involuntary or automatic. (1) The movements of the skeletal muscles (voluntary) are all due to influences brought to bear through the central nervous system. Every step that we take is the result of distinct acts on the part of nerve centers in the brain. (2) On the contrary the contractions of the heart are due to an inherent rhythmic tendency of the muscle itself. We express this fact by saying that cardiac muscle is automatic, and the same is true in a general way of all visceral muscles (involuntary). We must become familiar with the idea that stimuli from the nervous system not only excite muscular activity (as in the skeletal muscles) but also increase or decrease the degree of activity. The influence of the nervous system on the activity of automatic muscular tissue is the latter, *i.e.*, to increase or decrease it.

Tone.—The constant and insensible tendency to contract which exists under normal conditions is described as tone. It is really a mild, sustained contraction, and though it may vary in degree, it is rarely absent altogether.

The tone of the skeletal muscles is due to stimuli from the central nervous system that are not intense enough to cause motion but gives them a certain firmness and maintains a slight steady pull upon their attachments. In fractures the over-riding of the broken ends of a bone is often due to the contraction of the muscle that is the result of its tonicity. Although all muscles exhibit tone, visceral muscle is preëminent in its power to do so. The importance of this is obvious if one remembers that a satisfactorily high blood-pressure is partly dependent upon the muscles in the walls of the arteries remaining in a condition of tone throughout life. Likewise healthy digestion is dependent on the tone of the muscles of the stomach and intestines.

[3] See "Muscle sense," page 462.

The tone of visceral muscles is partly due to substances in the blood, *i.e.*, sodium, potassium and calcium salts, and secretions from the ductless glands[4] as well as stimuli from the nervous system.

Conditions of contraction.—Skeletal muscle is essentially a quick-acting tissue. It contracts quickly and relaxes promptly. In sharp contrast to this, the contractions of visceral muscle develop slowly, are maintained for some time, and fade out slowly. The contraction of any skeletal muscle is the result of a series of stimuli discharged rhythmically by the nerve cells innervating it. If one of these contractions is analyzed it will be found that there is a brief period after the muscle is stimulated before it contracts. This is called the latent period and is followed by a period of contraction, which in turn is followed by a period of relaxation. If we give 0.10 of a second as the reaction time, 0.01 might represent the latent period, 0.04 the contraction period, and 0.05 the relaxation period. It is easy to understand how this might vary, depending upon (1) the strength of the stimuli; (2) the duration of the stimulus; (3) the quality of the muscle substance; and (4) the temperature. Muscles do their best work at a certain optimum temperature which differs somewhat for different muscles. If the temperature is raised beyond a certain upper limit the muscle loses its excitability and becomes functionally depressed, entering finally the state of heat rigor, *i.e.*, a condition of permanent shortening.

Tetanus.—When a muscle receives a series of repeated stimuli so rapidly that there are no periods of relaxation, it remains in a condition of contraction as long as the stimuli are sent in, or until it loses its excitability from fatigue. A contraction of this kind is described as a compound contraction or *tetanus.*

Blood-supply and source of energy.—All varieties of muscular tissue are well supplied with blood-vessels which are supported and carried by the connective tissue. They do not penetrate into the cells, but each cell is bathed in lymph which exudes from the blood-vessels. One of the substances brought by the blood to the muscles is glucose which is stored in the cells as glycogen.[5] This represents chemical energy, which stimuli may transform into mechanical energy. Muscles may be compared to engines capable of converting chemical energy into mechanical. The transformation of energy which accompanies muscular activity is associated with the oxidation of glycogen and perhaps fat,

[4] See page 283. [5] See page 400.

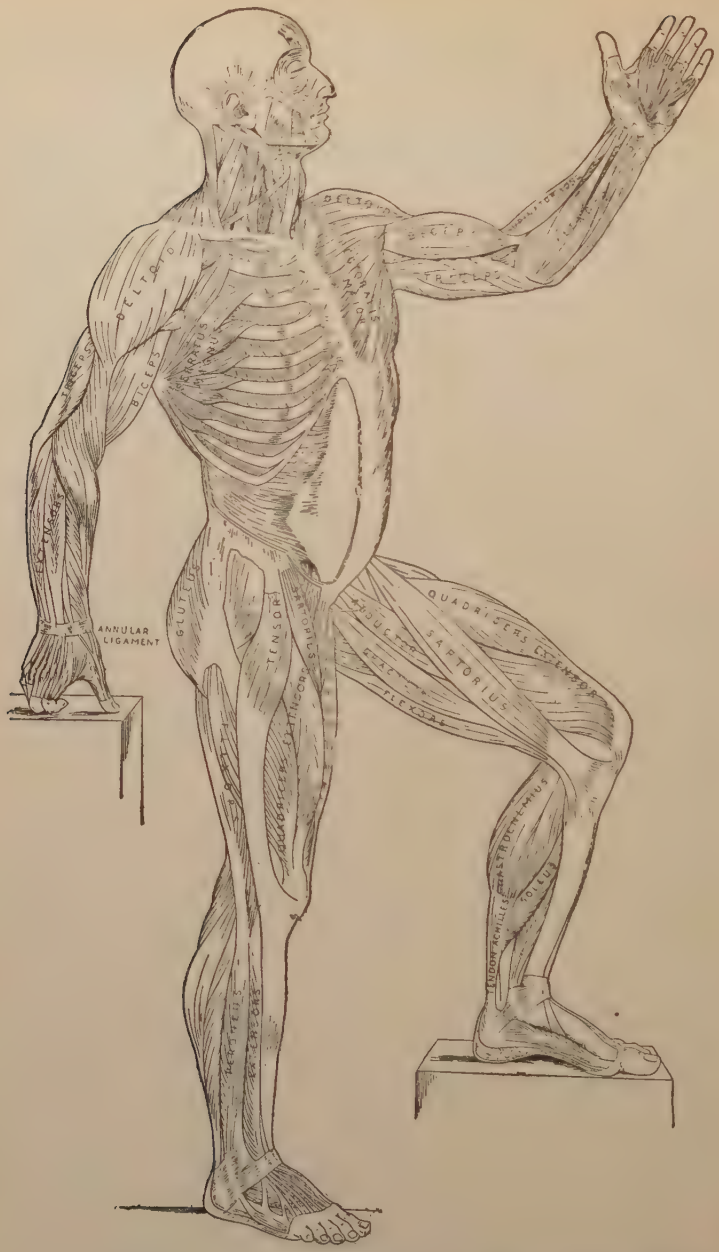


FIG. 66.—HUMAN BODY SHOWING MUSCLES (Right Side and Front).
Courtesy of William Wood & Co., and John Bale Sons & Danielsson, Ltd.

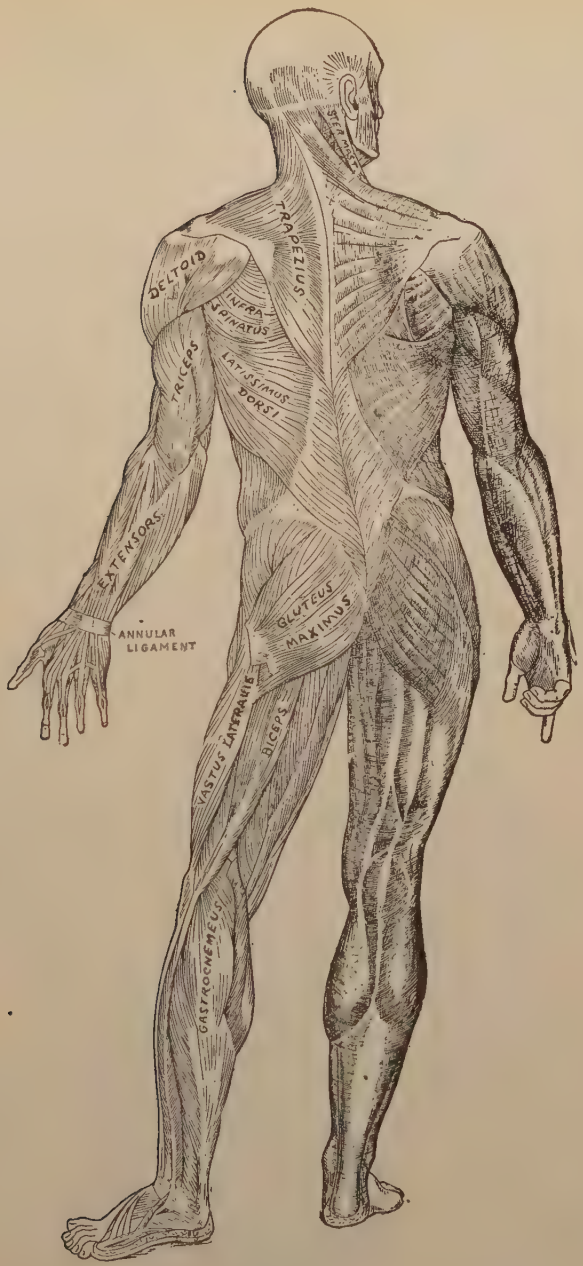


FIG. 67.—HUMAN BODY SHOWING MUSCLES. (Back.)
Courtesy of William Wood & Co., and John Bale Sons & Danielsson, Ltd.

and the formation of waste substances, *i.e.*, carbon dioxide, water, lactic and sarcolactic acid. At first these substances increase the excitability of the muscles enabling them to do more work, but this increased excitability is soon lost and excessive amounts have an opposite effect. These waste substances must be eliminated, and except in cases of prolonged contractions, the system is able to get rid of them readily.

Fatigue.—Prolonged contractions result in *fatigue*, and this means two things: (1) an accumulation of waste substances (carbon dioxide, lactic acid, and sarcolactic acid) which act as poisons, (2) a loss of nutrient material. A period of rest furnishes opportunity for the blood to carry these fatigue poisons to the excretory organs; and nutritive material from the digestive organs to the muscles. In cases of extreme fatigue resulting from prolonged overwork the fatigue poisons circulate in the blood and lessen the irritability of muscular tissue so that it fails to respond to stimuli. It has been demonstrated that the injection of the blood of a fatigued animal into a rested one will promptly bring on signs of fatigue. It must not be thought that the state which we ordinarily recognize in ourselves as fatigue is entirely muscular. The sense of fatigue is very complex and is often associated with such mental states as lack of interest, lack of will power, laziness, etc.

FUNCTIONALLY IMPORTANT SKELETAL MUSCLES

The skeletal muscles are usually called by their Latin names, and it is helpful to understand the meaning of these names, as they are often descriptive of some distinctive characteristic, such as their form, size, attachment, location, function, etc.

The majority occur in pairs. Only a few are single, and they are located about the median line. Muscles may be classified in several ways. The most helpful way is to classify them according to their location and function. It is most important to remember that skeletal muscles are usually arranged in antagonistic groups, one of which opposes the other. Thus the muscles located on the anterior surface of the arm and forearm are called flexors, and those located on the posterior surface are called extensors. The action of the flexors is to bend the arms, the action of the extensors is to extend or straighten the arm. When stimulated, either group of muscles must overcome the resistance of the opposing group. Therefore contraction takes place more slowly and evenly, and smoothness of movement is the result.

CHIEF MUSCLES OF HEAD, FACE, TONGUE, AND NECK

Muscles of the Head	Epicranial or Occipito-frontalis.	
Muscles of the Face	Muscles of the orbit and eyelids	Four recti. Two oblique. Levator palpebræ superioris. Orbicularis palpebrarum.
	Muscles of Mastication	Masseter. Temporal. Internal pterygoid. External pterygoid.
	Muscles of the Lips	Orbicularis oris. Buccinator.
Muscles of the Tongue	Genioglossus. Styloglossus.	
Muscles of the Neck	Platysma. Sternocleidomastoid.	

Muscles of the head.—The chief muscle of the head is the epicranial, or occipito-frontalis, which may be considered as two muscles, the occipital which covers the back or occiput of the

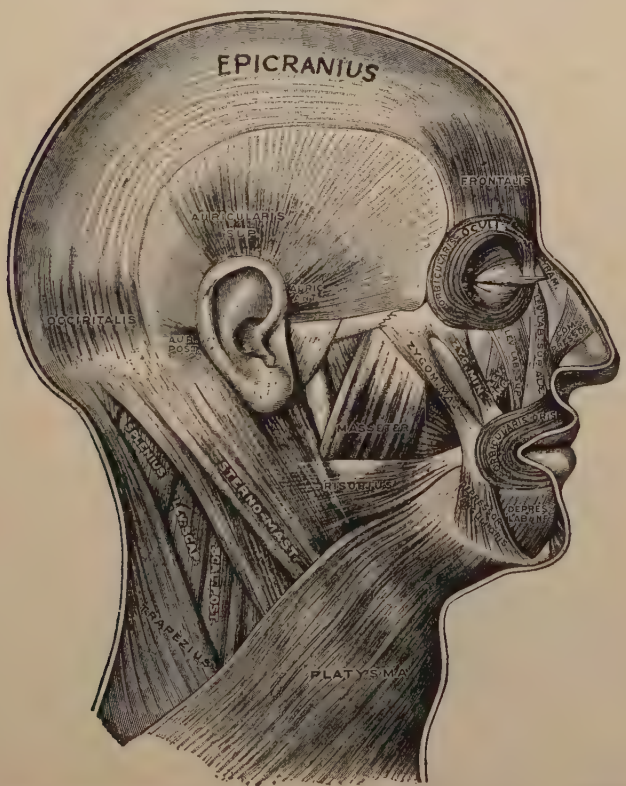


FIG. 68.—SUPERFICIAL MUSCLES OF HEAD AND NECK. (Gerrish.)

head, and the frontal which covers the front of the skull. The two muscles are held together by a thin aponeurosis extending over and covering the whole of the upper part of the cranium. The occipital takes its origin from the occipital bone and the mastoid portion of the temporal bone and is inserted into the aponeurosis. The frontal takes its origin from the aponeurosis, and is inserted into the tissues in the region of the eyebrows.

Action.—The frontal portion of this muscle is the more powerful; by its contraction the eyebrows are elevated, and the skin of the forehead thrown into transverse wrinkles.

Muscles of the face.—There are about thirty facial muscles; they are chiefly small, and only a few are considered. We group them as: (1) Orbital muscles, (2) Muscles of mastication, and (3) Muscles of the lips.

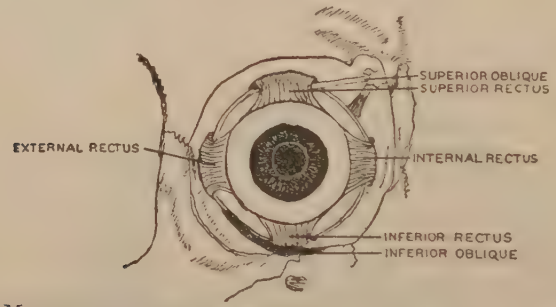


FIG. 69.—MUSCLES OF THE RIGHT EYEBALL WITHIN THE ORBIT. (Seen from the front.)

Muscles of the orbit and eyelids.—The orbit contains seven muscles; six of them are attached to the eyeball, and are arranged in three opposing pairs.

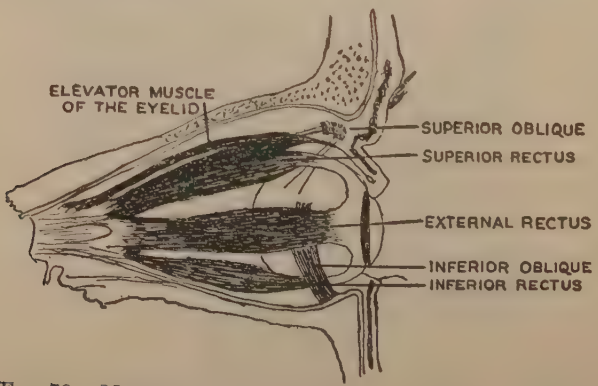


FIG. 70.—MUSCLES OF THE EYEBALL. (Seen from side.)

The Recti.—These four muscles called respectively, superior, inferior, internal and external, have their origin at the apex of the orbital cavity. Each muscle passes forward in the position which its name indicates and is inserted into the eyeball.

The Oblique.—There are two oblique muscles, called respectively superior and inferior. The superior oblique arises from the apex of the orbit, courses forward to the upper and inner angle of the orbit, where it passes through a ring of cartilage. Then it bends at an acute angle, passes around the upper part of the eyeball and is inserted between the superior and external recti. The inferior oblique arises from the orbital plate of the maxilla and passes around the under portion of the eyeball to its attachment between the superior and external recti.

Action.—The four recti acting singly turn the corneal surface of the eye, upward, downward, inward or outward, as their names suggest. The action of the two oblique muscles is somewhat complicated, but their general tendency is to roll the eyeball on its axis. These muscles do not act singly but rather coöperatively and with a high degree of coördination.

Levator palpebræ superioris (lifter of the upper lid).—It arises from the sphenoid bone, passes forward, and is inserted into the tarsal cartilage of the upper lid.

Action.—It raises the upper lid and opens the eye.

Orbicularis oculi[6] (circular muscle of the lid).—It arises from the nasal portion of the frontal bone, from the frontal process of the maxilla, and from a short fibrous band, the medial palpebral (tarsal) ligament. It spreads lateralward forming a broad thin layer which occupies the eyelid, and is inserted at the union of the upper and lower lid at the outer side of the eye. This is called the palpebral portion. A broader thicker part called the orbital portion surrounds the circumference of the orbit, spreads over the temple and downward on the cheek; its fibers form a complete ellipse, the upper ones being inserted in the frontalis muscle. (See Fig. 68.)

Action.—It serves as a sphincter muscle of the eyelids. The action of the palpebral portion is involuntary. It closes the lids gently as in sleep or blinking. The orbital portion is under the control of the will. The action of the entire muscle is to close the lids forcibly, drawing the parts toward the inner angle and tightening the brow.

[6] Also called Orbicularis palpebrarum.

Muscles of mastication.—They are: (1) the masseter (chewing muscle), (2) the temporal (temple muscle), (3) the internal pterygoid, and (4) the external pterygoid. These muscles can be located on the illustrations. They have their origin in one or more of the immovable bones of the skull, and are inserted into the movable lower jaw.

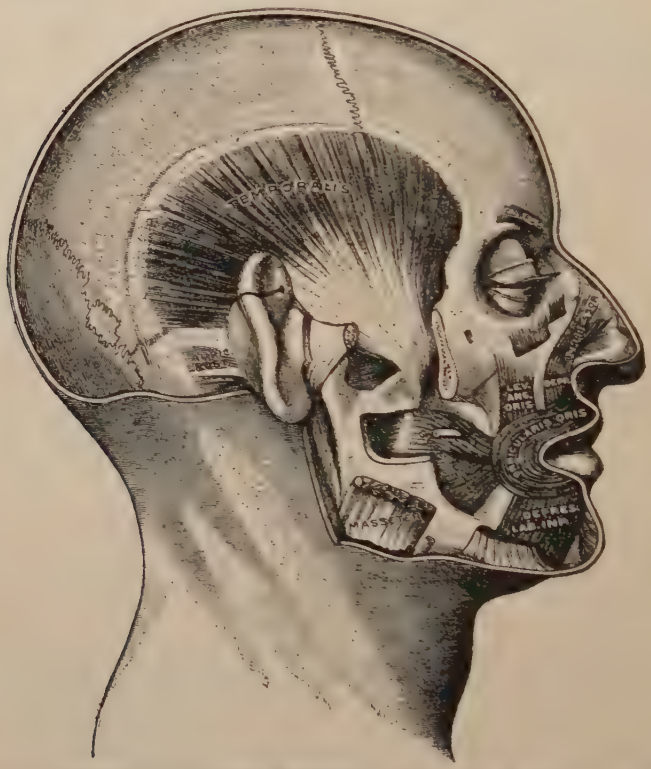


FIG. 71.—TEMPORAL AND DEEP MUSCLES ABOUT THE MOUTH. (Gerrish.)

Action.—The masseter, temporal and internal pterygoid raise the mandible against the maxillæ. The posterior fibres of the temporal retract the mandible. The external pterygoid assists in opening the mouth, and both acting together cause the lower jaw to protrude, so that the lower teeth are projected in front of the upper. The internal and external pterygoid of one side produce lateral movements of the jaw such as take place during the grinding of food.

Muscles of the lips.—We shall only consider two important muscles related to the orifice of the mouth.

Orbicularis oris.—It consists of numerous layers of muscular fibers which surround the opening of the mouth and pass in different directions. Some of the fibers are derived from other facial muscles which are inserted into the lips; some fibers proper to the lips pass in an oblique direction from the under surface of the skin through the thickness of the lips to the mucous membrane; other fibers connect the maxillæ and septum of the nose above with the mandible below.

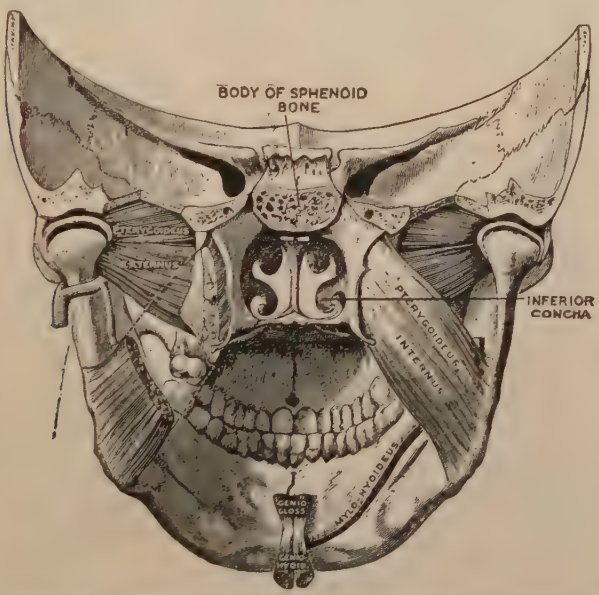


FIG. 72.—PTERYGOID MUSCLES. Viewed from behind, the back portion of the skull having been removed. (Gerrish.)

Action.—It causes compression and closure of the lips in various ways, *e.g.*, tightening the lips over the teeth, contracting them, or causing pouting or protrusion of one or the other.

Buccinator (trumpeter's muscle).—This muscle arises from the alveolar processes of the maxilla and mandible. Its different parts converge to the angle of the mouth, and are inserted into the orbicularis oris.

Action.—It compresses the cheeks so that during mastication the food is kept under pressure of the teeth.

Muscles of the tongue.—The tongue is made up of muscular tissue and is divided into two halves by a fibrous septum. In each half there are two sets of muscles; the *extrinsic* have their origin outside the tongue, and the *intrinsic* are contained

within it. Two of the extrinsic muscles are the genioglossus and the styloglossus.

Genioglossus.—The genioglossus has its origin on the inner surface of the mandible at the symphysis and spreads out in a fan-like form. It is attached to the body of the hyoid bone, and the whole length of the under surface of the tongue, in and at the side of the midline.

Action.—It thrusts the tongue forward, retracts it, and also depresses it.

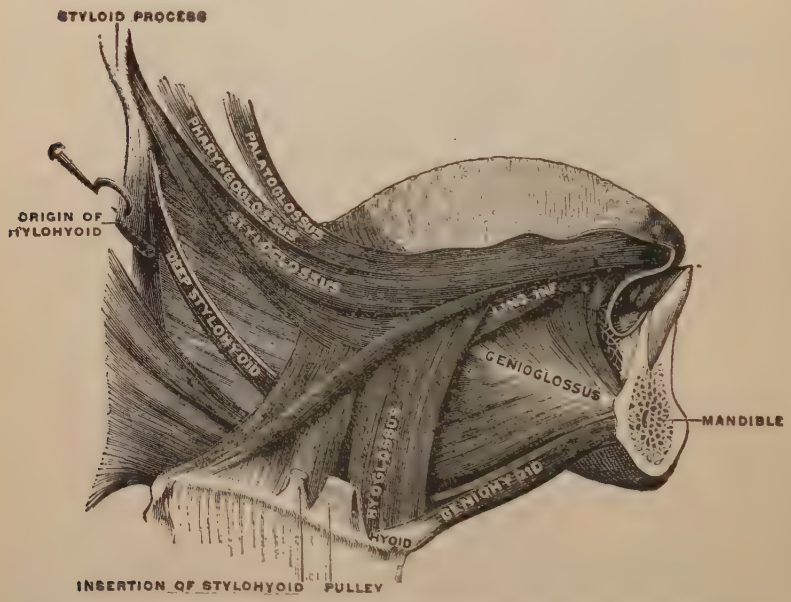


Fig. 73.—Muscles of the Tongue. Viewed from the right side. (Gerrish.)

Styloglossus.—The styloglossus has its origin in the styloid process of the temporal bone, and is inserted in the whole length of the side and under part of the tongue.

Action.—It draws the tongue upward and backward.

During general anesthesia these, together with all the other muscles, become relaxed, and it is necessary to press the angle of the lower jaw upward and forward in order to prevent the tongue from falling backward and obstructing the larynx.

Muscles of the neck.—Two superficial muscles of the neck are: (1) platysma, (2) sternocleidomastoid. (See Fig. 68)

Platysma (broad sheet muscle).—It arises from the skin and

fasciæ covering the pectoral, and deltoid muscles, and is inserted in the mandible and muscles about the angle of the mouth.

Action.—It depresses the mandible and draws down the lower lip and angle of the mouth.

Sternocleidomastoid.—The most prominent muscle of the neck is the sternocleidomastoid. It is named from its origin and insertion, arising from the upper part of the sternum and inner border of the clavicle and being inserted into the mastoid portion of the temporal bone. This muscle is easily recognized in thin persons by its forming a cord-like prominence obliquely situated along each side of the neck.

Action.—When one muscle acts alone, it flexes the head laterally, and rotates it carrying the face to the opposite side. Both muscles acting together (1) flex the head in a forward direction, and (2) serve as extraordinary muscles of inspiration, by raising the sternum and clavicles. If one of these muscles be either abnormally contracted or paralyzed, we get the deformity called *Torticollis* or wry neck.

CHIEF MUSCLES OF THE TRUNK

They may be arranged in five groups:—

1. **Muscles of the Back**	Trapezius. Latissimus dorsi. Sacrospinalis (Erector spinæ).
2. **Muscles of the Chest**	Pectoralis major. Pectoralis minor. Serratus anterior (Serratus magnus).
3. **Muscles of the Thorax**	External intercostals. Internal intercostals. Levatores costarum.
4. **Diaphragm**	
5. **Muscles of the Abdomen**	External oblique. Internal oblique. Rectus abdominis. Transversalis. Quadratus Lumborum.

Muscles of the back.—The muscles of the back are disposed in five layers, one beneath another. Our list includes only the two large muscles, trapezius and latissimus dorsi, which form the superficial layer, and the sacrospinalis which forms the fourth layer.

Trapezius.—The trapezius, so called because right and left together make a large diamond-shaped sheet, arises from the middle of the occipital bone, and from the processes of the seven cervical and the twelve dorsal vertebræ. The connection with the cervical vertebræ is through the medium of the *ligamentum nuchæ.*[7] (See Fig. 74.) From this extended line of origin the fibers converge to their insertion in the clavicle, the acromion process, and the spine of the scapula. It is a very large muscle,

[7] See page 51.

and covers the other muscles of the upper part of the back and neck, also the upper portion of the latissimus dorsi.

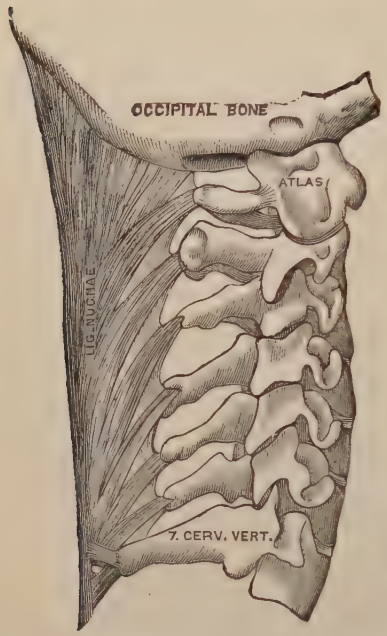


FIG. 74.—MUSCLES IN THE SUPERFICIAL LAYER OF THE BACK. (Gerrish.)

Action.—Contraction of the whole trapezius retracts the scapula and braces back the shoulder. If the shoulders are fixed it draws the head backward. When the upper fibers contract they raise the shoulder; when the lower fibers contract they help to depress the scapula. Contraction of the middle and lower fibers[8] rotates the scapula upward, and swings the glenoid cavity upward.

Latissimus dorsi.—The latissimus dorsi covers the lower part of the back. It arises from the lower six thoracic vertebræ, and through the medium of the lumbodorsal fasciæ[9], from the lumbar and sacral part of the spine, from the posterior third of the crest of the ilium, and from the lower three or four ribs. The fibers pass upward and converge into a thick, narrow band, which winds around and finally terminates in a flat tendon, which is inserted into the front of the humerus just below its head.

Action.—It depresses the humerus, draws it backward and rotates it inward.

Sacrospinalis.—The fourth layer of the muscles of the back is formed by the sacrospinalis (erector spinæ) which constitutes the greater part of the long rounded mass located on either side of the series of vertebral spinous processes. It arises from the lower and posterior part of the sacrum, the posterior portion of the iliac crest and the spines of the lumbar, and the lower two thoracic vertebræ. It is a compound muscle beginning below in a single mass which soon splits into three columns, called the iliocostals, the longissimus and the spinalis. Each of these consists of three parts.

[8] Movement around an imaginary axis from front to back through the center of the bone is considered rotation.

[9] The lumbodorsal fascia or lumbar aponeurosis is a deep investing membrane which covers the deep muscles of the back of the trunk.

These muscles end at different levels by a series of attachments to the ribs and vertebra all the way up the back to the occipital bone and the mastoid process of the temporal bone. As the muscle climbs up the back it does not relinquish one foothold before it establishes another. The result is not merely a continuity of structure but overlapping, as one segment begins back of the ending of the segment below it.

Action.—The several parts of this muscle have a complex action on the vertebral column, head, ribs, and pelvis. The muscle serves as an extensor of the vertebral column and assists in lateral movement and rotation. Portions of the muscle assist in extension, lateral movement, and rotation of the head. Other portions serve as accessory muscles of inspiration. The whole muscle helps in extension and lateral movement of the pelvis in walking.

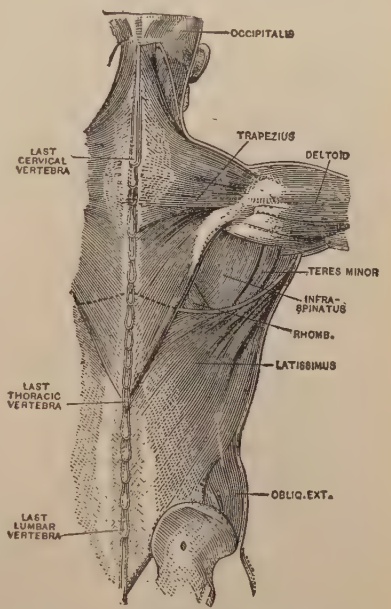


FIG. 75.—MUSCLES IN THE SUPERFICIAL LAYER OF THE BACK. (Gerrish.)

Muscles of the chest.—The chief bulk of the anterior muscular wall of the chest is made up of the pectoral and the serratus anterior muscles.

Pectoralis major.—The pectoralis major arises from the sternal end of the clavicle, the anterior surface of the sternum, the six upper ribs and the aponeurosis of the external oblique. The fibers converging form a thick mass, which is inserted by a tendon of considerable breadth into the upper part of the humerus.

Action.—If the arm has been raised the pectoralis major acting with other muscles[10] draws the arm down to the side of the chest. Acting alone it adducts and draws the arm across the chest, also rotates it inward.

Pectoralis minor.—The pectoralis minor is underneath and entirely covered by the pectoralis major. It arises from the surface of the third, fourth, and fifth ribs, near the cartilages, and is inserted in the coracoid[11] process of the scapula.

10 The latissmus dorsi and the teres major. For the latter see Fig. 84.
11 See Fig. 48 for coracoid process of scapula.

Action.—It depresses the point of the shoulder and rotates the scapula downward. In forced inspiration these two muscles help in drawing the ribs upward and expanding the chest.

Serratus anterior.—The serratus anterior (magnus) arises from the outer surfaces and superior borders of the upper eight or nine ribs and from the aponeuroses covering the intercostals. The fibers run upward and backward and are inserted in various portions of the ventral surface of the scapula.

Action.—It draws the shoulder forward as in pushing; *i.e.*, carries the scapula forward and raises the vertebral border. It also assists the deltoid in raising the arm.

Muscles of the thorax.—The most important muscles of the thorax are (1) the intercostals, and (2) the levatores costarum.

FIG. 76.—SACROSPINALIS, SUPERFICIAL VIEW. (Gerrish.)

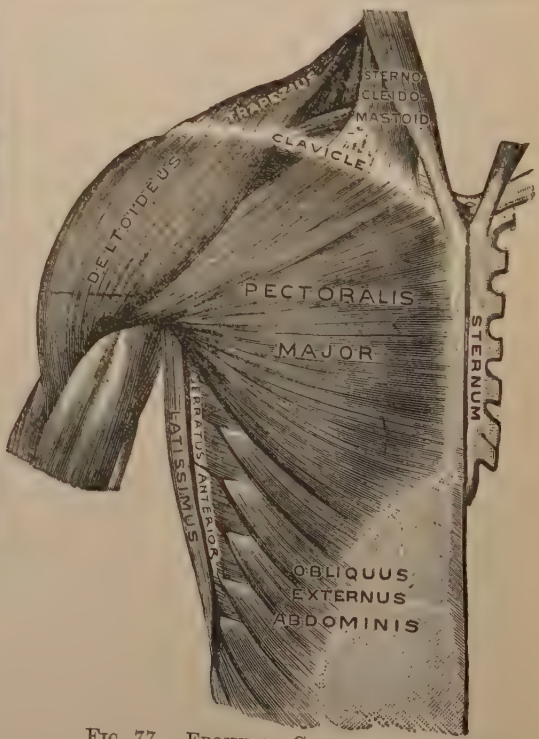


FIG. 77.—FRONT OF CHEST AND SHOULDER OF RIGHT SIDE, SUPERFICIAL MUSCLES. (Gerrish.)

Intercostals.—The intercostals are found filling the spaces between the ribs. Each muscle consists of two layers, one external and one internal, and as there are eleven intercostal spaces on each side, and two muscles in each space, it follows there are forty-four intercostal muscles. The fibers of these muscles run in opposite directions.

External intercostals.—The external fibers arise from the lower border of a rib, pass downward, and inward, toward the midline and are inserted into the upper border of the next lower rib.

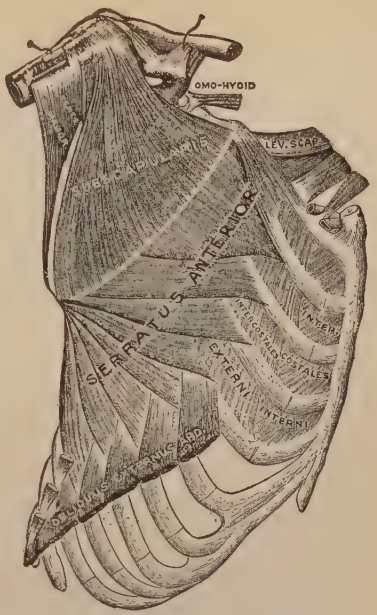


FIG. 78.—SERRATUS ANTERIOR OF RIGHT SIDE. The scapula has been turned backward and drawn outward. (Gerrish.)

Action.—They elevate the ribs, thereby increasing the chest cavity.

Internal intercostals.—The internal fibers arise from the lower border of a rib, run downward, and backward, and are inserted into the upper border of the next lower rib.

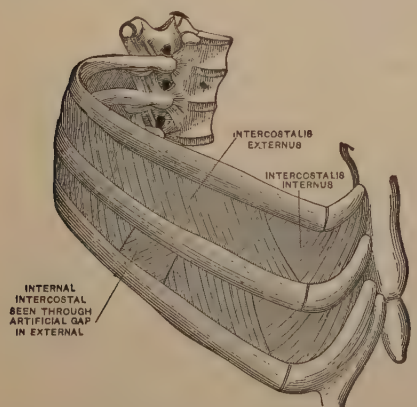


FIG. 79.—INTERCOSTAL MUSCLES IN RIGHT WALL OF THORAX. (Gerrish.)

Action.—Investigators disagree as to the functions of the internal intercostals, but it is considered probable that the portions between the ribs serve to contract, those between the costal cartilages to expand the chest cavity.

Levatores costarum.—The levatores costarum are twelve small slips that arise from the transverse processes of the vertebræ from the seventh cervical to the

eleventh thoracic. Each one spreads out in a fan-like manner as it descends to its insertion in the rib below.

Action.—The levatores costarum have little action on the ribs, they act as rotators and lateral flexors of the vertebral column.

Diaphragm.—The diaphragm is a dome-shaped, musculo-fibrous partition which forms the convex floor of the thoracic cavity and the concave roof of the abdominal cavity. The origin is from the circumference of the thorax, *i.e.*, by two vertical bundles called *crura*[12] at the sides of the lumbar vertebræ, from arches of lumbar fascia, from the lower boundary of the six lower ribs and the xiphoid process of the sternum. The fibers converge toward the central portion which is aponeurotic, and serves for the insertion of the muscular portion. It has three

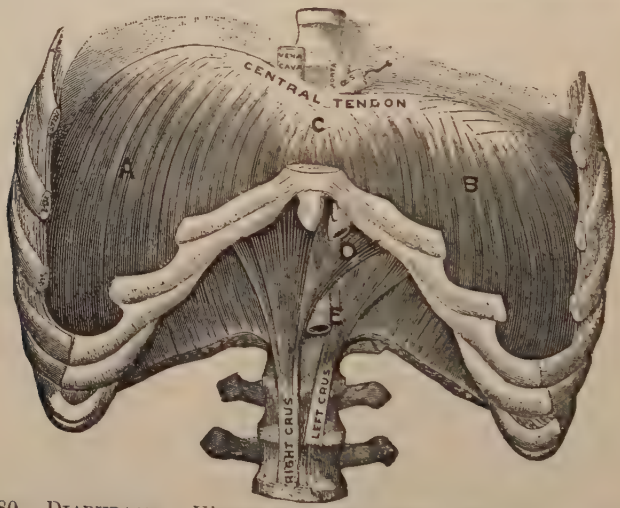


FIG. 80.—DIAPHRAGM. Viewed from in front. (Gerrish.) At *A* the liver and at *B* the cardiac end of the stomach are underneath the diaphragm and push it up; at *C* the tip of the heart pushes the diaphragm down. At *D* and *E* the esophagus and aorta penetrate it.

large openings: the aortic for the passage of the aorta, the largest artery of the body; the caval for the passage of the inferior vena cava, one the largest veins of the body; and the esophageal for the passage of the esophagus, or gullet; it has also some smaller openings for the passage of blood-vessels, nerves, etc. The upper or thoracic surface of the diaphragm is highly arched; the heart is supported by the central tendinous portion of the arch, the right and left lungs by the lateral portions, the right portion of the arch being slightly higher than the left. The lower or under

[12] Singular *crus*.

surface of the diaphragm is deeply concave, and covers the liver, stomach, pancreas, spleen, and kidneys.

Action.—The diaphragm is one of the principal respiratory muscles, and at times it assists the abdominal muscles in their functions. When the muscular portion contracts, the central tendon is pulled downward, so that the vertical diameter of the thorax is increased.

In forcible acts of expiration, and in efforts of expulsion from the thoracic and abdominal cavities, the diaphragm and all the other muscles which tend to depress the ribs, and those which compress the abdominal cavity, concur in powerful action to empty the lungs, to fix the trunk, and to expel the contents of the abdominal viscera. Thus it follows that the action of the diaphragm is of assistance in expelling the fetus from the uterus, the feces from the rectum, the urine from the bladder, and its contents from the stomach in vomiting.

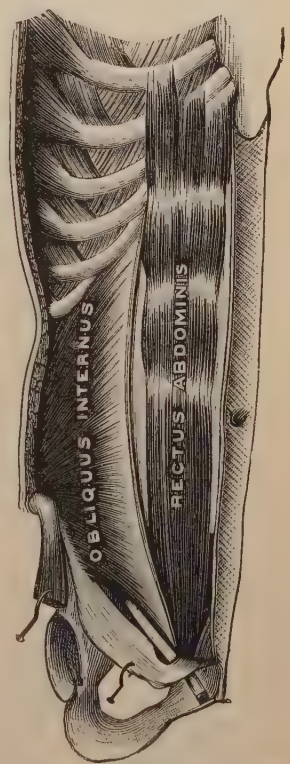


FIG. 81.—RECTUS ABDOMINIS AND OBLIQUUS INTERNUS OF RIGHT SIDE. (Gerrish.)

Muscles of the abdomen.—The chief muscles of the abdomen are: (1) external oblique, (2) internal oblique, (3) rectus abdominis, (4) transversalis, and (5) quadratus lumborum. Of these muscles, the rectus is in front, the quadratus is behind, and the contractile portion of the obliquus externus, obliquus internus, and transversalis are at the side.

External or descending oblique.—The strongest and most superficial of the abdominal muscles is the external oblique. It arises from the outer surface of the eight lower ribs. The fibers from the lowest ribs pass downward and are inserted into the anterior half of the iliac crest, the middle and the upper fibers pass downward and forward and terminate in the broad aponeurosis, which, meeting its fellow of the opposite side in the linea alba, covers the whole of the front of the abdomen. The lowest fibers of the aponeurosis are gathered together in the shape of a thickened

band, which extends from the anterior superior spine of the ilium to the pubic bone, and forms the well-known and important landmark, the *inguinal ligament*, more commonly known as Poupart's ligament from the anatomist who first described it.

Internal or ascending oblique.—The internal oblique muscle lies just beneath the external oblique. It arises from the inguinal ligament, the crest of the ilium, and slightly from the lumbodorsal fascia. Its fibers pass upward and forward and are inserted in the costal cartilages of the six lowest ribs, the linea alba and the crest of the pubes. At the outer border of the rectus muscle the remaining muscle fibers expand into a broad aponeurosis. This aponeurosis divides into two layers, one passing before, the other behind, the rectus muscle; they reunite at its inner border in the linea alba, and thus form a sheath for the rectus, extending from the xiphoid process to the crest of the pubes. At the lower part of the rectus the posterior layer of the aponeurosis is deficient.

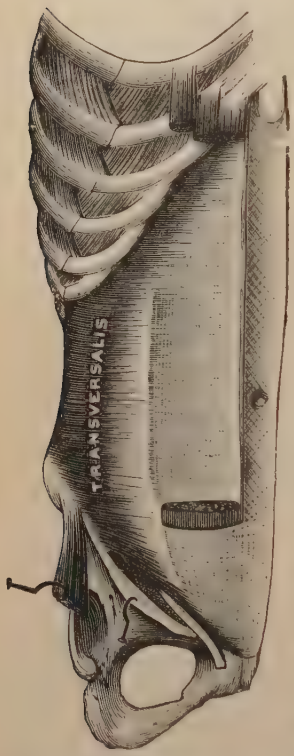


FIG. 82—TRANSVERSALIS ABDOMINIS OF RIGHT SIDE. (Gerrish.)

Rectus abdominis.—The rectus is a long, flat muscle, consisting of vertical fibers situated at the front part of the abdomen, and enclosed in the fibrous sheath formed by the aponeuroses of the internal oblique, the external oblique, and the transversalis muscles. It arises from the pubic bone, and is inserted into the cartilages of the fifth, sixth, and seventh ribs; it is separated from the muscle of the other side by a narrow interval which is occupied by the linea alba.

Transversalis.—The transversalis muscle lies beneath the internal oblique. The fibers arise from the six lower costal cartilages, the lumbodorsal fascia, the anterior half of the crest of the ilium, and the outer third of the inguinal ligament. The greater part of its fibers have a horizontal direction, and are inserted in the linea alba and the crest of the pubic bone.

Linea alba.—The linea alba, or white line, is a tendinous band

formed by the union of the aponeuroses of the two oblique and transversalis muscles, the tendinous fibers crossing one another from side to side. It extends perpendicularly, in the middle line, from the xiphoid portion of the sternum to the pubes. It is a little broader above than below, and a little below the middle it is widened into a flat, circular space, in the center of which is situated the umbilicus.

Quadratus lumborum.—The quadratus lumborum is a square, flat muscle which lies toward the back part of the abdominal wall. It arises from the posterior part of the crest of the ilium and the iliolumbar ligament,[13] and is inserted into the lower border of the twelfth rib and the transverse processes of the four upper lumbar vertebræ. The colon, the kidney, the psoas major and minor are in front of the quadratus lumborum. (See Fig. 86.)

Action of the abdominal muscles.—When these muscles contract, they compress the abdominal viscera, and constrict the cavity of the abdomen, in which action they are much assisted by the descent of the diaphragm. By these means they give assistance in parturition, defecation, micturition, and emesis. They also assist in respiration, flex the thorax on the pelvis, and are concerned with lateral bending and rotation at the spine.

The inguinal canal.—Between the abdominal muscles, parallel to, and about one-half inch above the inguinal ligament, is a tiny canal, about one and one-half inches long, called the inguinal canal This canal transmits the spermatic cord in the male, and the round ligament of the uterus in the female. The internal opening of the canal is called the *internal abdominal ring*, and is situated in the fascia of the transversalis muscle, midway between the spine of the ilium and the crest of the pubic bone. The canal ends in the *external abdominal ring*, which is in the tendon of the external oblique muscle.

Weak places in the abdominal walls.—The *internal* and *external abdominal rings*, described above, the *umbilicus*, and another ring situated just below the inguinal ligament, called the *femoral ring*, are considered weak places because they are so often the seat of *hernia*. Hernia,[14] or rupture, is a protrusion of a portion of the contents of a body cavity, and in this instance would mean a protrusion of a portion of the intestine or mesentery through one of these weak places. If it occurs in the umbilicus,

[13] The iliolumbar ligament connects the pelvis with the vertebral column.

[14] If the skull is injured so that a portion of the brain protrudes, it would also be correctly spoken of as hernia of the brain. Of course this is more unusual than abdominal hernia.

it is called *umbilical hernia*; in the inguinal rings, *inguinal hernia;* and in the femoral ring, *femoral hernia.* Conditions which favor hernia are (1) lifting, coughing, etc., which greatly increases the pressure of the abdominal contents against the body wall, and (2) lack of tone of the ventral abdominal wall which comes about in old age, or as the result of illness. The inguinal canal is larger in the male than in the female, hence inguinal hernia is more common in the male than in the female.

MUSCLES OF THE UPPER EXTREMITIES

A certain number of muscles situated superficially on the trunk are frequently grouped with the muscles of the upper extremities, as their function is to attach the upper limbs to the trunk and move the shoulders and arms. Of these, the two superficial muscles trapezius and latissimus dorsi we have mentioned as covering the back, and the pectoralis major and pectoralis minor covering the front of the chest, are the chief.

The muscles of the extremities are arranged in antagonistic groups, the action of one group opposing the action of the other. The movements of which the extremities are capable are flexion and extension, abduction and adduction, supination and pronation, circumduction and rotation.[15]

Functionally we may group the muscles of the upper extremities as follows:—

NAME OF MUSCLE		LOCATION	FUNCTION
Moving the Shoulder	Trapezius	Upper portion of back	Raises shoulder, depresses scapula and rotates it upward.
	Pectoralis minor	Chest, under pectoralis major	Depresses the point of the shoulder and rotates the scapula downward
	Serratus anterior	Upper two-thirds of side of chest	Draws the shoulder forward, carries the scapula forward and raises the vertebral border.
Moving the Arm	Deltoid	Covers the top of the shoulder	Abduction, forward and backward motion.
	Pectoralis major	Chest, from sternum to humerus	Adducts, draws the arm across front of chest and rotates it inward.
	Latissimus dorsi	Lower portion of back	It depresses the humerus, draws it backward and rotates it inward.
	Biceps	Anterior surface of arm	Flexes the elbow joint and supinates the forearm and hand.
	Triceps	Posterior surface of arm	Extension of forearm.
Moving the Forearm	Pronators	Anterior surface of forearm	Pronation.
	Supinators	Posterior surface of forearm	Supination.

[15] See page 72.

Deltoid.—The deltoid is a coarse, triangular muscle covering the top of the shoulder and the middle of the outside of the arm. It arises from the clavicle, acromion process, and spine of the scapula, extends downward, and is inserted into the middle of the shaft of the humerus, on the outer side. (See Figs. 77 and 84.)

Action.—It abducts—raises the arm from the side so as to bring it at right angles to the trunk, also draws the arm forward and backward.

FIG. 83.—MUSCLES OF THE FRONT OF THE RIGHT SHOULDER AND ARM. (Gerrish.)

FIG. 84.—MUSCLES OF THE DORSUM OF THE RIGHT SHOULDER AND ARM. (Gerrish.)

Biceps.—The biceps is a long fusiform muscle, occupying the whole of the anterior surface of the arm; it is divided above into two portions or heads, from which circumstance it has received its name. It arises by these two heads from the scapula, and is inserted into the radius.

Action.—The action of the biceps is complex, as it affects three joints. The muscle raises and draws forward the humerus at the shoulder joint, flexes the elbow joint, and supinates the

forearm and hand. The combination of these movements produces a simple act, *e.g.*, raising the hand to the mouth.

Triceps.—The triceps is situated on the back of the arm extending the whole length of the posterior surface of the humerus. It is of large size, and divided above into three heads; hence its name. Two of the heads have their origin in the humerus and one in the scapula. The three heads unite in a common tendon which is inserted into the olecranon of the ulna.

FIG. 85.—MUSCLES IN THE DORSUM OF THE RIGHT FOREARM AND HAND. (Gerrish.)

Action.—It is the great extensor muscle of the forearm, and is the direct antagonist of the biceps.

Muscles of the forearm.—The muscles covering the forearm have their origin in the humerus, radius and ulna, and are inserted into the carpals and phalanges. They are disposed in groups, the **pronators** and **flexors** being placed on the front and inner part of the forearm, and the **supinators** and **extensors** on the outer side and back of the forearm: they antagonize one another. The pronators turn the palm of the hand backward and, when the elbow is flexed, downward or prone. The supinators turn the palm of the hand forward, and, when the elbow is flexed, upward or into the supine position. The flexors and extensors have long tenonns, some of which are inserted into the bones of the wrist, and some into the bones of the fingers: they serve to flex and extend the wrist and fingers.[16]

MUSCLES OF THE LOWER EXTREMITIES

If we compare the muscles of the shoulder, arm, and forearm with those of the hip, thigh, and leg, we shall see that the anterior muscles of the former correspond roughly with the posterior muscles of the latter, the muscles of

[16] See page 112.

the hip, thigh, and leg, however, being larger and coarser in texture than those of the shoulder arm, and forearm.

Functionally we may group the most important muscles of the lower extremities as follows:—

	Name of Muscle	Location	Function
Moving the Thigh	Psoas magnus Iliacus	In the pelvis and upper part of thigh	*Flexes* thigh on pelvis, rotates femur outward.
	Gluteus maximus	Region of buttocks	*Extension*, external rotation and adduction.
	Gluteus medius	Under gluteus maximus	*Abduction* of the thigh and inward rotation.
	Gluteus minimus	Under gluteus medius	
	Adductor magnus	Medial part of thigh	*Adductor* and *flexor*.
	Adductor longus		*Adducts* and assists in flexing the thigh.
	Adductor brevis		*Adducts* and flexes the thigh.
	Adductor gracilis		*Adducts* thigh and flexes the leg.
	Sartorius	Front of thigh	*Flexes* the hip and knee-joints, rotates the thigh outward.
Moving the Leg	Biceps femoris Semitendinosus Semimembranosus	Hamstring — Back of thigh	*Flex* the leg upon the thigh and extend the thigh.
	Rectus femoris Vastus lateralis Vastus medalis Vastus crureus	Quadriceps — Front of thigh	*Extension* of leg, flexes the thigh.
Moving the Foot	Tibialis anterior Peroneus tertius	Front of leg	*Flexes* the foot.
	Tibialis posterior		*Extensor* of foot at the ankle joint.
	Gastrocnemius	Back of leg	*Flexes* leg and *extends* ankle.
	Soleus		Same as gastrocnemius.
	Peroneus longus Peroneus brevis	Outer part of leg	*Extensors.*

Psoas major (*magnus*)—The great loin muscle arises from the last thoracic and all the lumbar vertebræ with the included intervertebral cartilages. It extends downward and forward, then downward and backward, to its insertion in the small trochanter of the femur.

Iliacus.—This muscle and its relation to the psoas major is well shown in Fig. 86. It arises from the iliac fossa and is inserted

partly into the tendon of the psoas and partly into the small trochanter of the femur.

Action.—The psoas major and iliacus act as one muscle to flex the thigh on the pelvis, and rotate the femur outward.

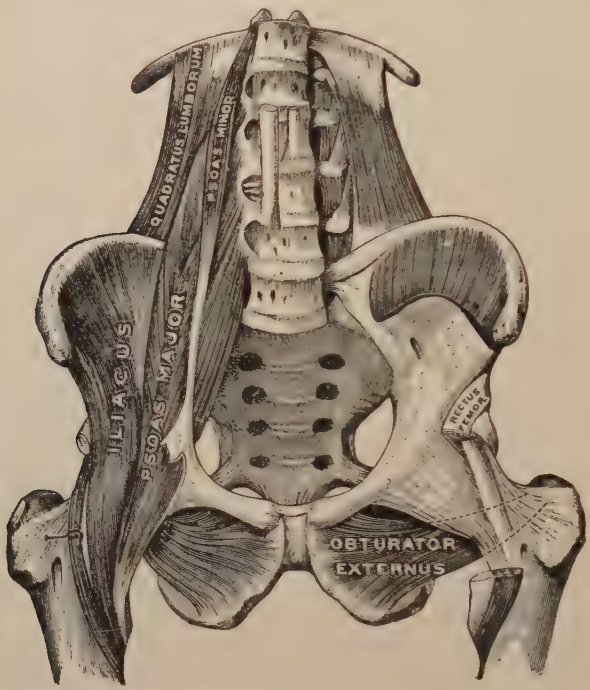


Fig. 86.—Psoas, Iliacus, and Obturator Externus Muscles. (Gerrish.)

Glutei muscles.—The three gluteal muscles are coarse in texture, and form the chief prominence of the buttocks.

Gluteus maximus arises from the ilium, sacrum, and coccyx, and is inserted into the great trochanter of the femur.

Action.—It is a powerful extensor of the hip joint. It also rotates the femur outward, and adducts the thigh.

Gluteus medius and gluteus minimus are under the gluteus maximus and almost entirely covered by it. They arise from the outer surface of the ilium and are inserted into the great trochanter.

Action.—Abduction of the thigh, and inward rotation.

Adductors.—The four adductor muscles are called respectively *magnus* (great), *longus* (long), *brevis* (short), and *gracilis* (slender). They are situated on the inner side of the thigh. The magnus arises from the ischium; the longus, brevis and gracilis from dif-

ferent portions of the pubic bone, and the first three are inserted into the inner side of the femur. The gracilis is inserted into the shaft of the tibia.

Action. — The first three (magnus, brevis, longus) adduct, flex and rotate the thigh outward. The gracilis adducts the thigh and flexes the leg.

Sartorius.— The sartorius,[17] or tailor's muscle, is a long, ribbon-like muscle which crosses the thigh obliquely from its origin in the anterior superior spine of the ilium to its insertion in the medial surface of the tibia. It was formerly supposed to be the muscle principally concerned in producing the posture assumed by the tailor in sitting crosslegged, hence its name.

Action.— It flexes the leg upon the thigh, and the thigh upon the pelvis, also rotates the thigh outward.

Quadriceps Femoris. — The quadriceps is a four-headed muscle that covers the front of the thigh, and is analogous to the triceps covering the back of the arm. Each head is described as a separate muscle: (1) rectus femoris, (2) vastus lateralis (vastus externus), (3) vastus medialis (vastus internus), and (4) vastus crureus (vastus intermedius.)

The rectus femoris arises by two heads, one from the anterior

[17] See Fig. 88.

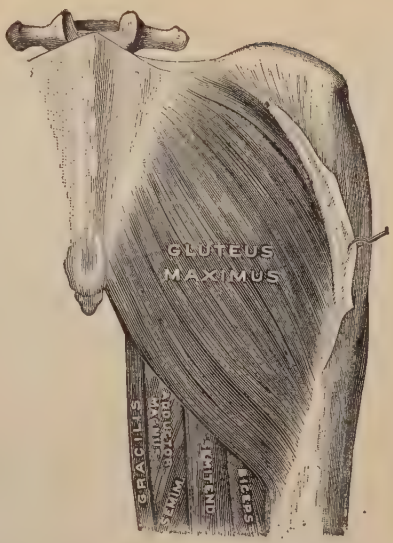


FIG. 87.—GLUTEUS MAXIMUS OF RIGHT SIDE. (Gerrish.)

FIG. 88.—SUPERFICIAL MUSCLES IN FRONT PART OF THE RIGHT THIGH. (Gerrish.)

inferior spine of the ilium, the other from above the brim of the acetabulum. The other three muscles arise from the femur. The fibers from these four muscles pass downward, and are inserted by one tendon into the tubercle of the tibia. The tendon passes in front of the knee joint, and the patella is a sesamoid bone developed in it.

Action.—The quadriceps is the great extensor of the leg; the rectus portion flexes the thigh, and antagonizes the action of the hamstring muscles.

Biceps Femoris.—The biceps arises by two heads, one from the ischium, and the

FIG. 89.—VASTUS CRUREUS OF RIGHT SIDE. (Gerrish.)

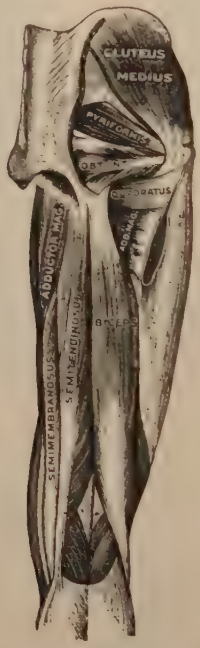


FIG. 90.—MUSCLES IN THE DORSUM OF THE RIGHT THIGH. (Gerrish.)

FIG. 91.—GASTROCNEMIUS OF RIGHT SIDE. (Gerrish.)

other from the posterior surface of the femur. It is inserted into the head of the fibula and the outer tubercle of the tibia.

Semitendinosus and Semimembranosus.—They arise from the ischium, and are inserted into the upper and inner part of the tibia. These three muscles, the biceps, semitendinosus, and semi-

membranosus, cover the back of the thigh, hence are named *posterior femoral*, or hamstring muscles.

Action.—They flex the leg upon the thigh, and extend the thigh.

Gastrocnemius and soleus.—The gastrocnemius and soleus form the calf of the leg. The gastrocnemius arises by two heads from the two condyles of the femur. The soleus is in front of the gastrocnemius. It arises from the tibia and fibula. The direction of both is downward, and they are inserted into a common tendon, the tendo calcaneus (tendo Achillis), which is the thickest and strongest tendon in the body, and is inserted into the calcaneus, or heel bone.

Action.—The gastrocnemius flexes the leg and extends the ankle. The soleus is a powerful extensor of the ankle.[18]

[18] The muscles described in this chapter represent a limited number of those found in the body. For further study the student is referred to one of the detailed text-books of anatomy.

SUMMARY

Muscular tissue is a motor tissue.

Correlated systems
- Skeletal System.
- Muscular System.
- Nervous System.

Characteristics of muscular tissue
1. Irritability or excitability—response to a stimulus.
2. Contractility—muscle becomes shorter, thicker, because each cell does.
3. Extensibility—muscle can be stretched, *i.e.*, property of individual cells.
4. Elasticity—muscle readily returns to original shape, *i.e.*, because each cell does.

Muscular tissue
- Cells become elongated.
- Intercellular substance is at a minimum.
- Reticular tissue—supporting framework.
- Well supplied with nerves and blood-vessels.

Classification
1. Striated, voluntary, skeletal.
2. Non-striated, involuntary, visceral.
3. Cardiac.

Striated (Voluntary, Skeletal)
1. Marked with transverse striæ.
2. Under control of will.
3. Attached to skeleton.
4. Muscle cells are long and spindle-shaped.
5. Reticular tissue framework carries blood-vessels and nerves.
6. Attached to bones, cartilage, ligaments, skin by means of *tendons*.
7. One muscle connects with another by means of an *aponeurosis*.
8. Muscles closely covered by sheets of fasciæ.
9. Deep fasciæ form annular ligaments in vicinity of wrist and ankle.
10. Origin—more fixed attachment.
11. Insertion—more movable attachment.

Non-striated (Involuntary, Visceral)
1. Not marked with transverse striæ.
2. Not under control of will.
3. Found in walls of blood-vessels and viscera.
4. Composed of spindle-shaped cells that contain just one nucleus.
5. Connective tissue framework carries blood-vessels and nerves.

Cardiac (Striated, Involuntary, Visceral)
1. Striated but not distinctly.
2. Not under control of will.
3. Made up of irregularly shaped cells.
4. Cells grouped in square bundles.
5. Connective tissue forms a supporting framework.

Stimuli
- Term used to describe influences which irritate or stimulate.
- They may be chemical; changes in concentration; mechanical or pressure; thermal or temperature; electrical and nervous.

Nerves
- Afferent—Carry impulses *from* periphery to brain, spinal cord, or ganglia. Afferent nerves connected with muscle are spoken of as sensory.
- Efferent—Carry impulses *to* the periphery from brain, spinal cord, or ganglia. Efferent nerves that end in muscles are spoken of as motor.

Varieties of Muscular Movements
- Voluntary—stimuli from central nervous system.
- Involuntary—automatic
- Cardiac —automatic
  - Stimuli from nervous system increase or decrease activity.

Tone
- Mild, sustained contraction existing under normal conditions.
- Skeletal muscles—stimuli from central nervous system.
- Visceral muscle preëminent in power to show tone. Satisfactory blood-pressure and healthy digestion dependent on it.
- Visceral muscles
  1. Substances in blood.
  2. Secretions from ductless glands.
  3. Stimuli from nervous system.

Conditions of Contraction
- Skeletal muscle—contracts quickly, relaxes promptly.
- Visceral muscle—contracts slowly, maintained for some time, fades out slowly.
- Heart muscle—contracts and relaxes unceasingly during life.
- Contractions
  - Result of series of rhythmic stimuli.
  - Consist of
    - Latent period ..... .01 sec.
    - Contraction period ..... .04 sec.
    - Relaxation period ..... .05 sec.
- Tetanus—compound contraction, due to stimuli being received too rapidly to allow for periods of relaxation.

Source of Energy
- Well supplied with blood from which glucose is obtained and stored as glycogen.
- *Glycogen* represents chemical energy.
- *Stimuli* transform chemical energy to mechanical energy.
- Chemical Change
  - Oxidation of glycogen and perhaps fat.
  - Waste substances
    - Carbon dioxide
    - Water
    - Lactic acid
    - Sarcolactic acid

Fatigue
- Loss of nutritive materials.
- Accumulation of waste substances.

FUNCTIONALLY IMPORTANT MUSCLES

	Name of Muscle and Where Found	Origin	Insertion	Function
Muscles of the Orbit and Eyelids	*Head* Epicranial or Occipito-frontalis — Occipital	Occipital bone	Aponeurosis — top of skull	Elevate the eyebrows, cause transverse wrinkles of forehead.
	Head Epicranial or Occipito-frontalis — Frontal	Aponeurosis — top of skull	Tissues of the eyebrows	
	Face — Superior rectus	Apex of orbit	Upper and central portion of eyeball	Rolls the eyeball upward.
	Face — Inferior rectus	Apex of orbit	Lower and central portion of eyeball	Rolls the eyeball downward.
	Face — Internal rectus	Apex of orbit	Midway on inner side of eyeball	Rolls the eyeball to which it is attached inward, the opposite one outward.
	Face — External rectus	Apex of orbit	Midway on outer side of eyeball	Rolls the eyeball to which it is attached outward, the opposite one inward.
	Face — Superior oblique	Apex of orbit	Eyeball — between superior and external recti	Rotates eyeball on its axis, directs cornea downward and lateralward.
	Face — Inferior oblique	Orbital plate of maxilla	Eyeball—near external recti	Rotates eyeball on its axis, directs cornea upward and lateralward.
	Face — Levator palpebræ superioris	Sphenoid bone	Tarsal cartilage of upper lid	Elevates upper lid and opens eye.
	Face — Orbicularis oculi	Nasal portion frontal bone, frontal portion of maxilla, and a short fibrous band, the medial palpebral ligament	Palpebral portion is inserted into lateral palpebral raphe	Palpebral portion closes the lids as in blinking. This action is involuntary.
			Orbital portion surrounds orbit—upper fibers blend with the frontalis muscle	Entire muscle closes lids forcibly.

NAME OF MUSCLE AND WHERE FOUND		ORIGIN	INSERTION	FUNCTION
Muscles of Mastication	Masseter	Zygomatic arch	Mandible	Raises the mandible and closes the mouth.
	Temporal	Temporal bone	Mandible	Raises the mandible and closes the mouth. Draws the mandible backward.
	Internal pterygoid	Palatine and maxilla	Mandible	Closes the mouth.
	External pterygoid	Sphenoid bone	Mandible	Moves the jaw forward and sideways. Helps to open the mouth.
Muscles of the Lips	Orbicularis Oris	Partition between nostrils and maxillæ	Mandible	Closes the lips. Sphincter of mouth.
	Buccinator	Alveolar processes of maxilla and mandible	Orbicularis oris	Compresses the cheeks, brings them in contact with the teeth.
Muscles of the Tongue	Genioglossus	Symphysis of mandible	Hyoid bone and whole length of tongue in and at the side of the midline.	Thrusts the tongue forward, retracts it, and also depresses it.
	Styloglossus	Styloid process of temporal bone	Whole length of side and under part of tongue	Draws the tongue upward and backward.
Muscles of the Neck	Platysma	Skin and fascia of the pectoral and deltoid muscles	Mandible and muscles about the angle of the mouth	Depresses the mandible, and draws down the lower lip.
	Sternocleidomastoid	Sternum and clavicle	Mastoid portion of temporal bone	Both acting together flex the head on the chest or neck, and serve as extraordinary muscles of respiration.

	Name of Muscle and Where Found	Origin	Insertion	Function
	Muscles of the Trunk			
Muscles of the Back	Trapezius	Occipital bone, ligamentum nuchæ, and spinous processes of the seven cervical and the twelve dorsal vertebræ	Clavicle, acromion process, and spine of scapula	Upper fibers raise shoulder. Middle fibers rotate the scapula. Lower fibers help to depress scapula.
	Latissimus dorsi	Lower six thoracic vertebræ, lumbar, and sacral part of spine, crest of ilium and lower three or four ribs	Front of the humerus	Depresses the humerus, draws it backward, and rotates it inward.
	Sacrospinalis Outer Division: Iliocostalis Middle Division: Longissimus Inner Division: Spinalis	Lower and posterior part of sacrum, posterior portion of the ilia, and spines of the lumbar vertebræ	Series of attachments to ribs and vertebræ all the way up the back to the occipital bone and mastoid process of temporal bone.	Serves as an extensor of the vertebral column and assists in lateral movement and rotation. Portions of the muscle assist in extension, lateral movement, and rotation of the head. Other portions serve as accessory muscles of inspiration. The whole muscle helps in extension and lateral movements of the pelvis in walking.
Chest	Pectoralis major	Clavicle, sternum, six upper ribs and external oblique	Upper part of humerus	It adducts and draws the arm across the chest, also rotates it inward.
	Pectoralis minor	Outer surfaces of 3d, 4th and 5th ribs	Scapula	Depresses the shoulder and rotates the scapula downwards.
	Serratus anterior	Surfaces and superior borders of upper eight or nine ribs	Various portions of the scapula on ventral side	Draws shoulder forward as in pushing. Carries scapula forward and assists in raising arm.

NAME OF MUSCLE AND WHERE FOUND		ORIGIN	INSERTION	FUNCTION
Thorax	External intercostals	Arise from lower border of each upper rib	Upper border of next lower rib	Elevate the ribs.
	Internal intercostals	Arise from lower border of each upper rib	Upper border of next lower rib	Portions between the ribs serve to contract, those between the costal cartilages to expand the chest cavity.
	Levatores costarum	Transverse processes of vertebræ from 7th cervical to the 11th thoracic	Outer surface of the ribs between the tubercles and angles	Act as rotators and lateral flexors of the vertebral column.
	Diaphragm	Internal circumference of the thorax, *i.e.*, by two crura, from arches of lumbar fascia, from lower border of six lower ribs, and xiphoid process	A central aponeurotic tendon	Principal respiratory muscle, modifies size of chest and abdominal cavity. Aids in expulsion.
Abdomen	External or descending oblique	Outer surface of lower eight ribs	Anterior half of iliac crest and broad aponeurosis, meeting its fellow of opposite side in linea alba	Compresses abdominal viscera.
	Internal or ascending oblique	Inguinal ligament, outer crest of the ilium, and the lumbodorsal fascia	Costal cartilages of six lowest ribs, linea alba, and crest of pubis	Compresses the abdominal viscera.
	Rectus abdominis	Pubic bone	Costal cartilages of 5th, 6th, and 7th ribs	Compression of the abdominal viscera.

NAME OF MUSCLE AND WHERE FOUND			ORIGIN	INSERTION	FUNCTION
Abdomen		Transversalis	Lower six costal cartilages, lumbodorsal fascia, crest of ilium, and outer third of the inguinal ligament	Linea alba and crest of the pubis	Compression of the abdominal viscera.
		Quadratus lumborum	Crest of the ilium, and iliolumbar ligament	Twelfth rib and transverse processes of four upper lumbar vertebræ	Draws last rib downward, both muscles acting together flex the trunk.
Upper Extremity		Deltoid	Clavicle, acromion process, and spine of scapula	Middle of shaft of humerus	Raises the arm from the side, also draws it forward and backward.
		Biceps	Scapula	Radius	Raises and draws forward the humerus at the shoulder joint, flexes the elbow joint, and supinates the forearm and hand.
		Triceps	Scapula and posterior surface of the humerus	Ulna	Extension of forearm.
	Pronators	Pronator teres (front of forearm)	Humerus and ulna	Radius	Pronation of the hand.
		Pronator quadratus (lower quarter, front of forearm, close to the bones)	Volar surface of ulna	Body of radius	Pronation of the hand.
	Flexors	Flexor carpi radialis (front of forearm)	Humerus	Base of 2d metacarpal bone	Flexion and slight pronation of hand.
		Flexor palmaris longus (front of forearm)	Humerus	Palmar aponeurosis	Flexes the wrist, assists in flexing the elbow.
		Flexor carpi ulnaris (front and inner border of forearm)	Humerus and ulna	Pisiform, hamate, and 5th metacarpal	Flexion of the hand.

NAME OF MUSCLE AND WHERE FOUND			ORIGIN	INSERTION	FUNCTION
Upper Extremity	SUPINATORS	Brachio-radialis or long supinator (outer and front part of lower fourth of arm and forearm)	Humerus	Lower portion of radius	Flexion of the elbow joint and assists in supination of hand.
		Supinator brevis (deep in upper third of outer part of forearm)	Lateral condyle of humerus	Radius	Supination.
	EXTENSORS	Extensor carpi radialis longus (outer border of forearm)	Humerus	2d metacarpal bone	Extension and abduction of hand.
		Extensor carpi radialis brevis (outer border of forearm)	Humerus	3d metacarpal bone	Extension and abduction of hand.
		Extensor carpi ulnarus	Humerus and ulna	5th metacarpal bone	Extension of wrist.
Lower Extremity		Psoas magnus (in the pelvis and upper part of thigh)	Last thoracic and all the lumbar vertebræ with included intervertebral cartilages	Small trochanter of femur	Flexes thigh on pelvis, rotates femur outward.
		Iliacus	Iliac fossa	Partly in tendon of psoas, and partly in small trochanter of femur	Same as psoas magnus.
		Gluteus maximus (largest)	Ilium, sacrum, and coccyx	Great trochanter of femur	Extension of the hip joint, external rotation, and adduction of the thigh
		Gluteus medius (middle)	External surface of the ilium	Great trochanter of femur	Abduction of the thigh, and inward rotation.
		Gluteus minimus (smallest)	External surface of the ilium	Great trochanter of femur	Abduction of the thigh, and inward rotation.

NAME OF MUSCLE AND WHERE FOUND			ORIGIN	INSERTION	FUNCTION
Lower Extremity	INTERNAL FEMORAL	Adductor magnus	Ischium	Inner side of femur	Adducts, flexes and rotates the thigh outward.
		Adductor longus	Pubic bone	Inner side of femur	Adducts, flexes and rotates the thigh outward.
		Adductor brevis	Pubic bone	Inner side of femur	Adducts, flexes, and rotates the thigh outward.
		Adductor gracilis	Pubic bone	Shaft of tibia	Adducts thigh and flexes the leg.
	ANTERIOR FEMORAL	Sartorius (front and inner side of thigh between ilium and tibia)	Anterior superior iliac spine	Medial surface of the tibia	Flexes the hip and knee joints. Rotates the thigh outward.
		Quadriceps femoris arises by four heads:—			
		1. Rectus femoris	Ilium and acetabulum	Tibia	Extend the leg and flex the thigh.
		2. Vastus lateralis	Femur		
		3. Vastus medialis	Femur		
		4. Vastus crureus	Femur		
	POSTERIOR FEMORAL	Biceps Femoris	Ischium and femur	Fibula and tibia	Flex the leg upon the thigh and extend the thigh.
		Semitendinosus	Ischium	Tibia	
		Semimembranosus	Ischium	Tibia	

		Name of Muscle and Where Found	Origin	Insertion	Function
Lower Extremity	Flexors	Tibialis anterior (front and outer side of leg)	Tibia and interosseous membrane	First cuneiform and first metatarsal bone	Flexion of the foot.
		Peroneus tertius (front of leg, dorsum of foot)	Fibula and interosseous membrane	Fifth metatarsal bone	Flexion of the foot.
	Extensors	Tibialis posterior (back of leg and inner part of foot)	Tibia and fibula	Navicular bone, three cuneiform, cuboid, 2d, 3d, and 4th metatarsal bones	Extension of the foot at the ankle joint.
		Peroneus longus (outer side of leg and sole of foot)	Tibia and fibula	Base of 1st metatarsal and first cuneiform bones	Extension of the foot.
		Peroneus brevis (outer side of leg and foot)	Fibula	5th metatarsal bone	Extension of the foot.
		Gastrocnemius	Femur	Tuberosity of the calcaneus	Flexes the leg and extends the ankle.
		Soleus	Fibula and tibia	Tuberosity of the calcaneus	Same as gastrocnemius.

CHAPTER VII

THE NERVOUS SYSTEM.—DIVISIONS OF THE NERVOUS SYSTEM; NERVE TISSUE; THE REFLEX ACT

If we recall our comparison of the human body to a coöperative community made up of industrial units, each one specially concerned with its own task, yet dependent upon the well-being and successful work of all the other units, it is obvious that some means of communication would be essential. In our modern cities the telephone meets this need. In the human body the nervous system meets a similar need, and many others: for it controls human thought and conduct; gives us the power to perceive and appreciate the world about us; to see, to move, to hear, to talk; is the main factor in the control of the internal organs; and in addition, is constantly furnishing the body knowledge of its environment. This knowledge (stimuli) is received by sense organs (end-organs of nerves), conducted along sensory nerves to the appropriate centers, and relayed from the centers by means of motor nerves to the muscles or groups of muscles concerned. Some telephone calls have to be relayed through a number of exchanges, to the main exchange, *i.e.*, the very center of the system, other calls can be transferred in a local

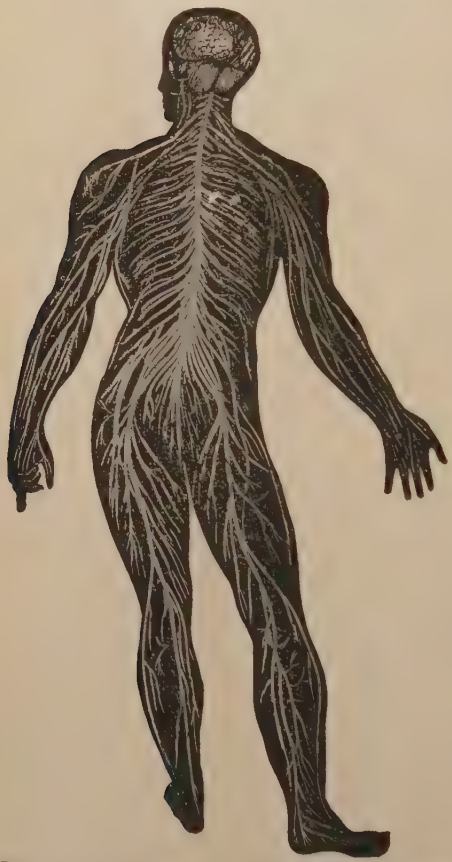


FIG. 92.—DIAGRAM ILLUSTRATING THE BRAIN, SPINAL CORD AND SPINAL NERVES.

or subsidiary exchange without going to the main exchange. Just so in the human body, to meet some needs stimuli are relayed through many nerve centers to the main centers (brain), while other needs can be cared for in local or subsidiary centers, even without any knowledge on the part of the main centers. In other words, some of our adjustments are conscious and require the coöperation of the highest center we possess, *i.e.*, the brain. Other adjustments, very important to our well-being, such as the motion of the stomach and intestines, are made unconsciously, *i.e.*, are cared for in subsidiary centers.

Just as the telephone system has a definite plan of exchanges connected by wires which ramify to all parts of the city, so we find the nervous system has a definite plan of centers (masses of nerve tissue) connected by nerves which ramify to all parts of the body.

From the standpoint of location and function the nervous system may be classified in two ways according to the following outlines:—

- **Nervous System**
  - **Central Nervous System**
    - Brain
      - Cerebrum.
      - Cerebellum.
      - Mid-brain.
      - Medulla Oblongata.
      - Pons Varolii.
    - Spinal cord.
  - **Peripheral Nervous System**
    - Cranial nerves, and end-organs.
    - Spinal nerves, and end-organs.
    - Sympathetic nervous system.

The peripheral portion of the nervous system includes nerve fibers and ganglia which control the functions of the viscera and are not under the will. They form the autonomic system and justify us in classifying the nervous system according to function.

- **Nervous System**
  - **Central Nervous System**
    - Spinal cord.
    - Spinal nerves, and end-organs.
    - Brain
      - Cerebrum.
      - Cerebellum.
      - Mid-brain.
      - Medulla Oblongata.
      - Pons Varolii.
    - Cranial nerves, and end-organs.
  - **Autonomic[1] Nervous System**
    1. Parasympathetic system includes the cranial autonomics, and the sacral autonomics.
    2. Sympathetic system includes, (1) centers in the cervical, thoracic and lumbar regions of the cord, (2) the sympathetic ganglia and their fibers, and (3) the great plexuses that are stimulated by impulses from the vertebral ganglia.
    3. Enteric system includes the plexuses in the walls of the alimentary tract.

[1] This classification is an adaptation of Langley's and is perhaps the simplest basis for the study of the autonomic system in relation to organic therapy. For other classifications see Gray's Anatomy, 21st edition, page 976, or Herrick's Introduction to Neurology, 3rd edition.

The central nervous system.—This is also known as the cerebrospinal or voluntary nervous system. It includes: (1) those parts of the brain that are concerned with consciousness and all mental activities, (2) the parts of the brain, cord and their nerves that control the skeletal muscles, (3) the end-organs of all the sensory nerves, including those of the special senses.

The autonomic nervous system.—This term means self-acting and includes all those parts of the nervous system which innervate: (1) all plain muscular tissue in the body, (2) the heart, and (3) the glands. As plain muscular tissue enters into the structure of all the viscera, this division of the nervous system is sometimes called splanchnic or visceral. It is also called involuntary because it is not under the control of the will, but it must not be thought of as an independent system, rather as a closely correlated division of the whole nervous mechanism.

Nerve tissue.—Nerve tissue enters into all parts of the nervous system. Like all other tissues it is composed of cells, but the cells are differentiated from other cells in that their protoplasm is extended, often to a distance of two or three feet, to form thread-like processes or conductors. The cells and their processes are held in place by a peculiar form of tissue called neuroglia or glia tissue. The cells of the nervous system are called neurons.

Neuroglia.—This is derived from the ectoderm, and consists of cells called glia cells that give off numerous fine processes which extend in every direction and intertwine among the nerve cells and processes, forming a supporting network.

Properties of nerve tissue.—Nerve tisue possesses the following marked characteristics: (1) irritability (excitability), or the power to respond to stimulation, and (2) conductivity or the power to transmit the stimuli or nerve impulses to other cells.

NEURONS

Neurons vary greatly in size, shape and number of processes, but always consist of a cell-body and processes. These two parts make up a complete nervous entity. The nervous system consists of an enormous number of these neurons supported by neuroglia tissue. Connective tissue forms protective membranes covering different parts of the system, and in addition blood-vessels and lymph-channels are provided for nutritive and respiratory purposes.

1. The cell body.—The body of a typical nerve cell consists of a mass of granular cytoplasm surrounding a large, well-defined nucleus. Lying in the cytoplasm are fibrils which extend into the processes, and Nissl bodies. The quantity of Nissl or chromophilic[2] substance is variable depending upon the fatigue of the cell, rested cells show a relatively greater amount. The loss of chromophilic substance is called chromatolysis. It occurs in fatigue, certain fevers, asphyxia, and injury to the axon. From the angles of the cell body processes are given off.

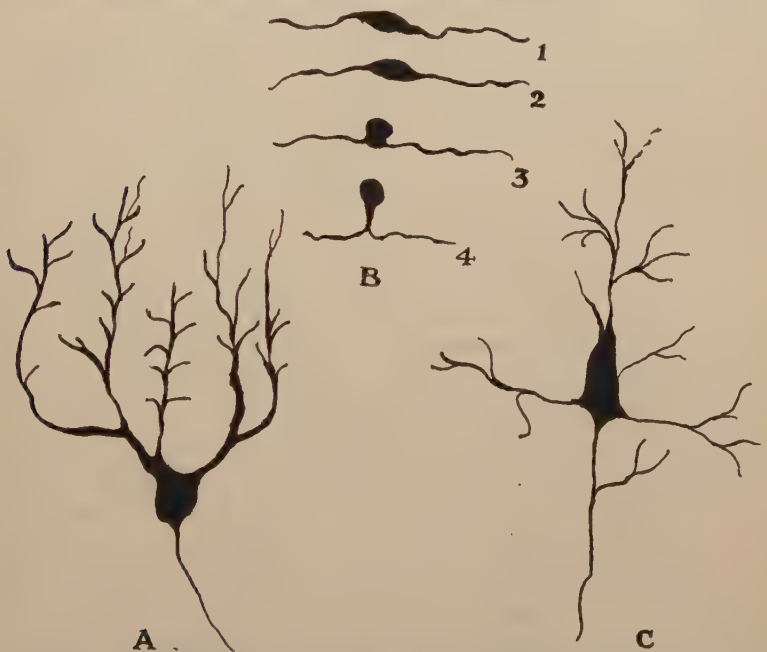


FIG. 93.—DIFFERENT TYPES OF NEURONS. *A*, cell of Purkinje from the cerebellum. *B*, pear-shaped cells of the spinal sensory ganglia, *1* is a bipolar cell, 2, 3 and 4, show how it gradually develops into the unipolar pear-shaped cell of the ganglion. *C*, pyramidal cell from cerebral cortex.

2. The cell processes.—The cell processes are named as follows:—*Dendrites or dendrons.*—These processes are usually short and rather thick at their point of origin. They have a rough outline, diminish in caliber as they extend farther from the cell body, and branch in a tree-like manner. The number of dendrites varies.

Axons, or axis cylinder processes, also called neuraxons.—These processes differ from the dendrites in the following partic-

[2] The bodies are called chromophilic (color loving) because they take stains readily, especially methylene blue.

ulars:—(1) They may be longer; in some instances their length may equal half a man's stature, (2) They have a smooth outline and diminish in caliber very little, (3) They give off one or more minute side branches called *collaterals*.

Function of the cell body.—The cell body is the source of energy and affords nutriment to its processes, as is proven by the fact that if a nerve fiber is cut, the part separated from the cell body dies.

Function of the processes.—The essential function of the processes is conduction of nerve impulses either to the cell body, or from the cell body. Processes which carry impulses *to* the cell body are called *afferent*, and those which carry impulses *from* the cell body are called *efferent*.

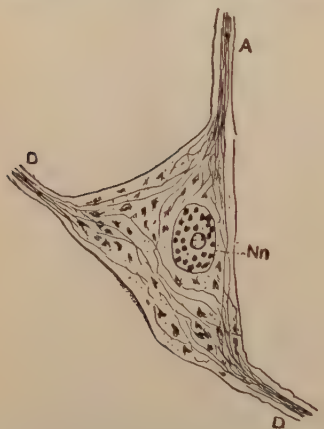


FIG. 94.—CELL BODY. *A*, axon, *D*, *D*, dendrites, *Nn*, nucleus with contained nucleolus. The dark spots indicate Nissl or chromophilic bodies, the lines represent fibrils in the protoplasm of the cell. (Burton-Opitz.)

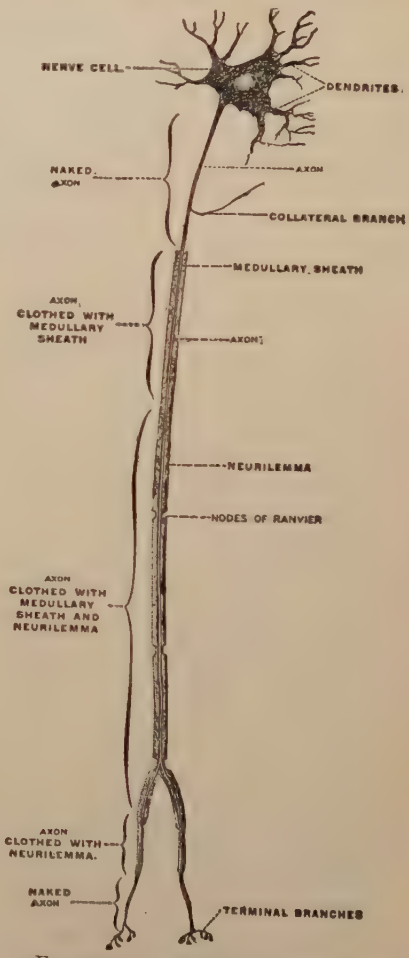


FIG. 95.—A MOTOR NEURON FROM A VENTRAL OR MOTOR HORN OF THE SPINAL CORD. (Modified from Gerrish.)

Function of the neuron.—Its function is to receive the nerve

impulse and to convey it to other cells. The structure is such that normally it can conduct in only one direction. Consequently each neuron possesses a distinct polarity, and the general arrangement of each neuron depends in a large measure upon the connections which it must establish with other neurons for functional purposes. Neurons are designated as afferent, receptor or sensory and efferent, motor or effector, depending on whether they carry impulses from the periphery to the center, or from the center to the periphery. Certain neurons which carry impulses from the sensory neurons to motor neurons are designated as central connecting or internuncial neurons.

Nerve fiber.—Nerve fibers do not exist independent of nerve cells, but always as outgrowths of these cells. These fibers as they extend away from the cell may become surrounded with sheaths and are of two kinds: medullated, or white fibers; and non-medullated, or gray fibers.

Medullated fiber.—If one looks at a medullated nerve fiber under the microscope, it is found to consist of three parts:—

(1) A central core which is the fiber; (2) immediately surrounding the fiber is a sheath, or covering, of a semi-fluid, fatty substance called *medulla or myelin sheath.* It is to this fatty substance that medullated nerve fibers owe their white color. (3) External to the myelin sheath is a thin membrane completely enveloping the nerve fiber and forming the outer covering called the *neurilemma.*

Function of the myelin sheath.—It is thought that the myelin sheath protects and insulates the nerve fiber. It is possible that this sheath prevents the deflection of nerve impulses from their intended course, in some such way as the insulation of an electric wire prevents the current from taking a path other than the one desired.

Nodes of Ranvier.—At regular intervals along the course of a medullated nerve fiber, the myelin sheath is interrupted and the neurilemma is brought close to the axon. These constrictions are the *nodes of Ranvier.* In each internodal segment the neurilemma is seen to have a nucleus. Medullated nerve fibers may be very long, but the diameter is very minute.

Non-medullated fiber.—Non-medullated nerve fibers (*fibers of Remak*) do not differ in any respect from the medullated nerve fibers save in the absence of the myelin sheath, the fiber being directly invested by the neurilemma. Owing to the absence of the

myelin sheath, the non-medullated fibers do not appear white, but present a gray or yellow color.

Synapse.—It has never been demonstrated that neurons are actually joined to each other anatomically. The fine branches of an axon of one neuron interlace or dovetail with the branches of a dendrite of another neuron, forming a *synapse*. The nerve impulse traveling through a nerve cell must cross a microscopic gap at the synapse to enter the next neuron. It is believed that conditions at the synapse may be such as to inhibit or facilitate[3] the passage of impulses. Normally there is some resistance to the passage of impulses from one neuron to another, and this may be increased or decreased due to changes in the synapses or the cell bodies. Consequently the function of synapses seems to be, (1) offering a variable amount of resistance to the passage of impulses, and (2) acting as valves and thus preventing the return of an impulse over a fiber by which it has been transmitted.

End-organs.—End-organs are of different types in accordance with their function and may be classified according to the part of the body in which they are found.

1. Nerve fibers which terminate in the brain or spinal cord split up into a number of fibrils called *end arborizations* which form synapses with the dendrites of other neurons.

2. Sensory nerve fibers ending at the periphery of the body terminate in two ways:—(*a*) *Inter-epithelial arborizations* is the most common mode of termination of sensory nerves. The nerve

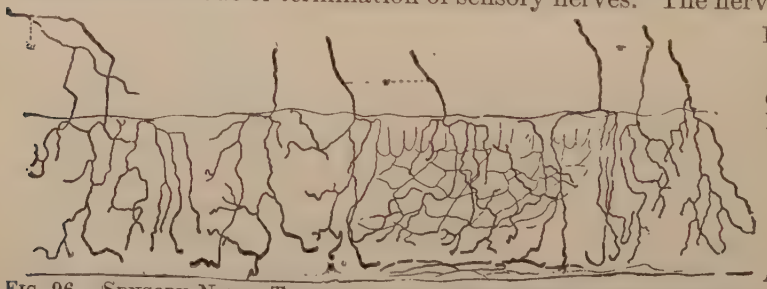


FIG. 96.—SENSORY NERVE TERMINATIONS IN STRATIFIED PAVEMENT EPITHELIUM. *A.-B.* The Epithelium. *C.-D.* Subcutaneous Tissue. (Kirkes.)

fibers pass to the surface either in the skin or mucous membrane; the neurilemma and myelin sheath disappear, the naked fiber subdivides into minute *arborizations* that ramify between the epithelial cells of the surface of the body. This method is the one in which nerves terminate in various glands, hairs, teeth, tendons, etc. (*b*) *Organules.*—Some of the highly complex special sensa-

[3] See page 129. Bahnung.

tions need *special end-organs* for their reception. The axon subdivides into arborizations and these are surrounded by connective tissue capsules. The different varieties of *tactile corpuscles*, the *organ of Corti*, for the auditory nerve, and the *rods* and *cones* of the retina may be cited as examples of organules.

3. Motor nerve fibers intended to stimulate a muscle to activity terminate by a subdivision of the axon (the neurilemma and myelin sheath fading out), each branch of the axon ending in a flat nodule of granular material lying on the muscle fiber. This terminal mass is the *motor end-plate*.

4. Motor nerve fibers ending in involuntary muscles (such as in the viscera) terminate in a *plexus* or network of non-medullated fibers in the viscera.

Formation of nerves.—The nerve fiber of each neuron is, as has been described, of microscopic diameter, but when a number of these nerve fibers are bound together in a bundle we have the plainly visible nerves, such as are seen in dissections of the body. Between the individual nerve fibers is a small amount of connective tissue called *endoneurium*, which serves to bind the fibers together into bundles, or *funiculi*, connective tissue called *perineurium* surrounds each funiculus in the form of a sheath and all the funiculi are held in a connective tissue covering called *epineurium*. This contains many blood-vessels and nerves.

The nerves branch frequently throughout their course, and these branches often meet and fuse with one another, or with

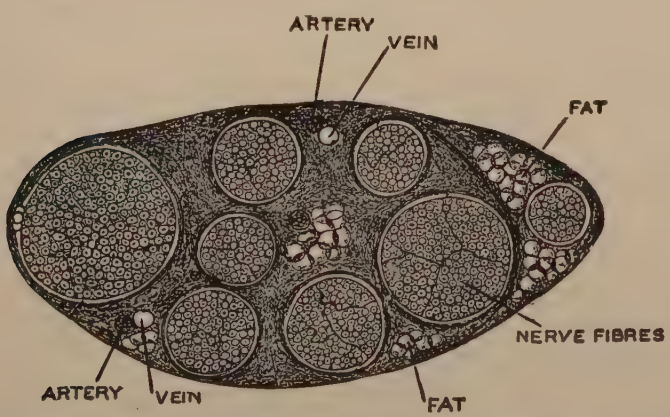


FIG. 97.—TRANSVERSE SECTION OF THE SCIATIC NERVE OF A CAT ABOUT × 100. This nerve consists of eight bundles (funiculi) of nerve fibers. Each bundle has its own wrappings (perineurium) and all the bundles are embedded in connective tissue (epineurium) in which arteries, veins, and fat cells can be seen.

the branches of other nerves, yet each axon always remains quite distinct. The nerve is thus merely an association of individual fibers which have very different activities and which may function entirely independently of one another. Most nerves are mixed nerves containing both afferent and efferent fibers. Perhaps the best idea of the arrangement of nerves in a trunk can be obtained from a cross section of a nerve such as is seen in Fig. 97.

Nucleus.—A grouping of the cell bodies of several neurons if within the central nervous system is called a *nucleus*.

Ganglion.—A small group of nerve cells outside the brain and spinal cord is called a ganglion. Ganglia appear in the course of the cranial and spinal nerves and form the mass of that part of the autonomic system which lies on either side of the vertebral column.

Center.—A group of neurons regulating a certain function is called a *nerve center*. It may be either a nucleus or a ganglion, as these two terms refer to an anatomical entity, and the term center refers to a functional entity. For instance, the rate of respiration is controlled by a center in the medulla oblongata, and odor is interpreted by a center in the cerebrum. In order to control an organ the center must be in communication with the organ by means of nerve fibers and end-organs specially adapted to receive and transmit impulses. Usually the fibers which connect the centers with the organs they control do not extend all the way, but terminate in masses of gray matter which serve as relay stations where they form synapses with other neurons that carry their impulses onward, possibly to one or more relay stations, or directly to the organ. There may be one or several relay stations. In any such series, the neuron first to be stimulated is called the neuron of the first order, and the succeeding neurons are called neurons of the second, third, and fourth order, etc.

Gray and white matter.—The cell bodies of neurons and many of their processes are grouped together into what we call gray matter. Gray matter is found in the cortex of the brain, the core of the spinal cord, and making up the nuclei and ganglia.

The medullated processes of cell bodies are grouped together, as described, into nerves, and these nerves constitute what we call white matter. It will therefore be seen that the gray matter contains the cell bodies and the synapses where the adjusting of sensory to motor neurons takes place, and the white matter is made up of the conductors of nerve impulses.

THE REFLEX ACT

In the same way that the *nervous system* may be reduced to a simple unit designated as the neuron, so *nervous action* may be reduced to the so-called reflex act, which means a response to a sensory stimulus. Just as the neuron forms the building stone of the nervous system, so the reflex act forms the functional basis

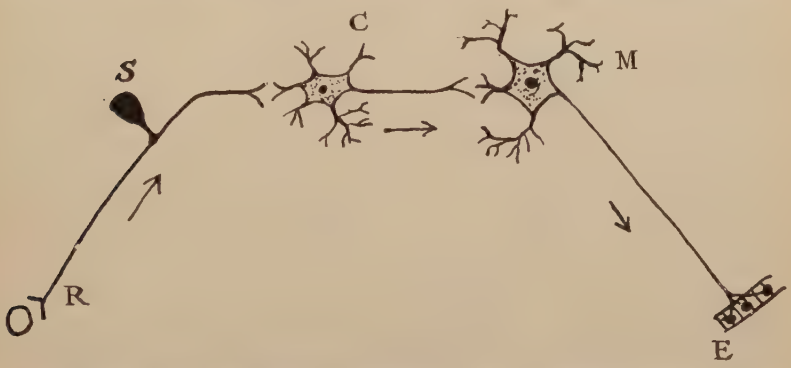


FIG. 98.—A REFLEX CIRCUIT CONSISTING OF A SENSORY, CENTRAL, AND MOTOR NEURON. *S*, sensory cell; *C*, central cell; *M*, motor cell; *R*, receptor; *E*, effector mechanism.

of nervous activity. At least two neurons enter into the formation of a reflex circuit (arc), a receptor or sensory neuron and an effector or motor neuron.

A receptor or sensory neuron is one in which the afferent process ends in a receptor of one kind or another. An effector or motor neuron is one in which the efferent process ends in a muscle or gland cell. Neurons which are interposed between other neurons are called central connecting or internuncial neurons.

A simple reflex circuit may consist of a sensory and a motor neuron. It is doubtful if there are any two cell reflexes in the adult vertebrate body. Most reflex circuits consist of a sensory neuron, one or more central neurons, and a motor neuron or of complexes of each of these.

Figure 98 illustrates a reflex circuit consisting of a sensory, central, and motor neuron.

On applying an appropriate stimulus to the receptor ending of the sensory neuron, an impulse is generated which passes along the afferent process to the cell body of the neuron, thence along the efferent process across the synapse through the central neuron and across another synapse to an afferent process of the motor

neuron, then through the cell body and an efferent process to the muscle or gland cell where action is produced.

Because of its likeness to a telephone system the peripheral end of the sensory nerve is often called the receptor (telephone transmitter). The processes are called conductors (telephone wires), the synapses and cell bodies are called adjusters (telephone op-

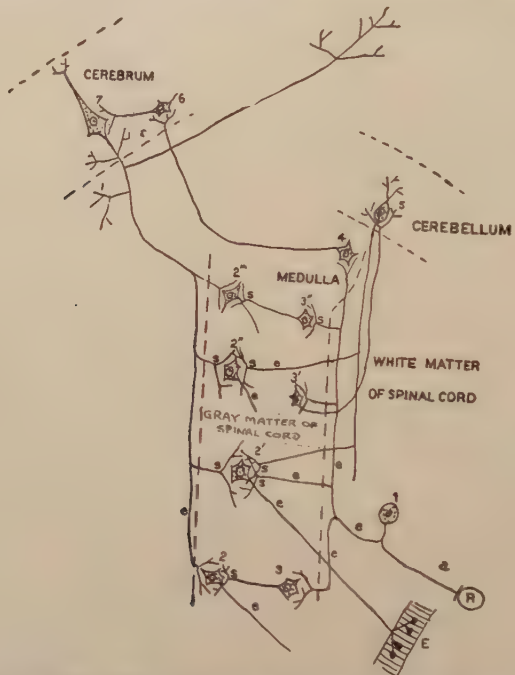


FIG. 99.—DIAGRAM TO ILLUSTRATE SOME REFLEX CIRCUITS OF THE CEREBROSPINAL SYSTEM, SHOWING A NUMBER OF CENTRAL AND MOTOR CELLS WITH THEIR SYNAPSES. 1, sensory cell in spinal ganglion; 2, 2′, 2″, 2‴, motor cells; 3, 3′ 3″, 4, 5, 6, 7, correlation cells. *a*, afferent process; *e*, efferent process; *s*, synapse. *R*, receptor; *E*, effector. The parallel vertical dotted lines enclose the gray matter. Outside these lines is the white matter of the spinal cord. (Adapted from Huxley-Lee.)

erators), and the ending in muscle or gland cell an effector (telephone receiver). The receptor receives the stimulus, transforms it to a nerve impulse, and passes it on to the afferent process. In the adjusting mechanism the nerve impulse may be transferred across some synapses rather than others for it must be remembered that each neuron forms synapses not simply with one neuron as in Fig. 98, but probably with many, as in Fig. 99.

When cells in the volitional centers enter into the reflex circuit the resulting action is due to volition or is voluntary,

as we say. In Fig. 99 the circuit starting at *R* and running through to the cerebral cell may represent a voluntary circuit. Many activities that are mediated in the ganglia, spinal cord and lower centers in the brain are entirely involuntary, *i.e.*, those controlling circulation, respiration, digestion, etc. Between the simplest forms of involuntary activity and the higher activities[4] that involve consciousness, memory or control are many types of activities varying in complexity, in number of centers involved, in degree of consciousness and control.

Classification of reflexes.—In relation to the kind of response brought about by a stimulus, reflex circuits may be classified as:—(*a*) *Simple* reflexes in which a single muscle or gland is involved, (corneal reflex.) (*b*) *Complex* reflexes, in which several muscles or glands are affected, the response remaining perfectly coördinated (patellar reflex[5] and the ankle-jerk.) (*c*) *Spreading* reflexes in which a large number of muscles in different parts of the body are involved. (*d*) *Tonic* or continuous reflexes in which the response following a stimulus lasts as a rule much longer than the stimulus. In many cases it becomes tonic in character. This result is frequently obtained when the nervous system is extremely irritable as after the administration of strychnin. (*e*) *Clonic or periodic* reflexes in which a stimulus may cause a certain response to be repeated a number of times at regular intervals, (sneezing, coughing, hiccoughing, swallowing, and trembling.) (*f*) *Association* or *perception* reflexes in which a definite mental picture is the stimulus to produce the reaction, (flow of saliva on smelling well-cooked food, sympathetic yawning.) (*g*) *Antagonistic reflexes* in which certain muscles of the body are

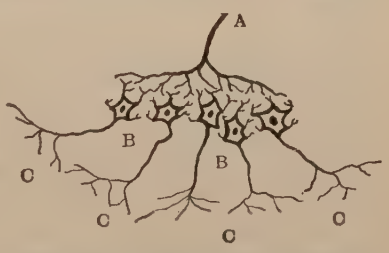


FIG. 100.—DIAGRAM TO ILLUSTRATE A SPREADING REFLEX. *A*, axon dividing into terminal branches which connect with cells *B*, *B*. These cells send their fibers *C*, *C*, *C*, *C*, to supply a number of different muscles.

[4] For discussion of levels of reaction consult Psychology for Nurses, Chapter IV, Muse, M. B. Saunders Co.

[5] Patellar reflex is the name given to the jerk of the foot caused by tapping upon the patellar ligament while the leg is crossed, or suspended across the edge of a table or chair. The impulses generated are conveyed to the sciatic center and thence to the quadriceps femoris muscle, which contracts and extends the leg. The varying intensity of this reflex is indicative of the irritability of the entire nervous system. Injuries to the cord may abolish this reflex entirely. Lesions of the higher centers increase its intensity.

antagonistic to each other. A stimulus which contracts one may result in the relaxation of its antagonist. Or the relaxation of one set of muscles may cause the contraction of another. (Flexors and extensors of arm or legs; coats of involuntary muscle.) (*h*) *Alternating reflexes* in which antagonistic reflexes occur in sequence, (rhythmic kicking.)

Reflex time.—This term is applied to the time elapsing between the application of a stimulus and the response. Reflex time varies in different individuals and in the same individual under different conditions, depending upon: (1) the strength of the stimulus—the stronger the stimulus the more prompt the response; (2) the nature of the stimulus, for example the response to sound is more prompt than that to light; and (3) the number of synapses through which impulses are transmitted determines to some extent the length of time required for responses.

Nature and speed of nerve impulses.—The nature of a nerve impulse is not known. We know that nerve fibers may be stimulated artificially by several means, and the practical result is similar to the result obtained were the nerve stimulated by the natural physiological impulse. The nerve fiber has no power to initiate a nerve impulse, but serves merely as a conductor of the impulse.

There are four means usually applied to the artificial stimulation of a nerve fiber, *viz.*, chemical, thermal, mechanical, and electrical. The latter is the most usual. That the true physiological impulse is none of these can readily be proven. But both electrical and chemical changes are associated with the conduction of nerve impulses, and the generally accepted theory at the present time is that a nerve impulse is a form of energy of a physico-chemical nature, and the physical phenomena are of an electrical nature, though not identical with an electrical current.

The speed at which an impulse travels along a nerve fiber is found to be about 120 meters (393 ft.) per second.

Identity of nerve impulses.—The generally accepted belief is that nerve impulses are identical in character and vary only in intensity. According to this the impulses carried by a sensory nerve are similar in character to those carried by a motor nerve and yet the result is different. This difference is thought to be due: (1) to the nature of the part stimulated by the nerve impulses, and (2) to differences in degree of intensity of the stimuli. Normally impulses start at the receiving end-organs of a nerve

fiber, but they can be induced at any part of the nerve fiber. When this happens the brain projects the resulting sensation to the part containing the receptors of the fibers stimulated. This explains why patients who have suffered an amputation refer the pain in the stump to the part that has been removed. The pressure of the surgical dressings, or new tissue on the nerve fibers is comparable to tapping a telegraph wire between stations, and the message received is interpreted as coming from the station, which in the body is the receptor.

Reaction of nerve-endings.—As previously stated, each type of receptor is sensitive to only one kind of stimuli. If, however, an unusual stimulus is applied, the sensation aroused is similar to the sensations resulting from the usual stimulus, for example, pressure on the eyes, *i.e.*, the receptors of the optic nerve, gives rise to a sensation of light, because light is the usual stimulus. This is equally true of nerve centers. If they are stimulated in an unusual way, they interpret the stimuli as being of the usual kind, which is the reason why a blow on the head, or a fall that jars the spinal cord is likely to stimulate the sight center, and flashes of light are seen.

Summation of stimuli.—Stimuli which are so slight that they fail to produce a response are described as subminimal. A succession of subminimal stimuli will produce a response, due to the fact that each successive stimulus renders the nerve cell more sensitive. This is known as the summation of stimuli. Excessive stimulation of neurons will cause changes which interfere with their functioning, and excessive stimulation of nerve centers will result in their depression.

Bahnung or facilitation.—An impulse which is made to pass through a certain set of neurons and their synapses a great many times, gradually breaks down the resistance in this path, and future impulses from the same source will pass readily through this same pathway. Because of this each repetition of an act renders its performance easier. This constitutes the basis of habit formation, memory, and character, and is the controlling factor for the habitual involuntary response of muscles to stimulation.

Diffusion of impulses.—The gray matter of the brain and cord consisting as it does of cell bodies, dendrites and axons, contains many synapses, and this means that incoming impulses have many possible nerve paths open to them. Normally the resistance offered at the synapses prevents their too wide diffu-

sion, and the formation of pathways reënforces this limitation. However, a strong stimulus may produce a great diffusion of impulses through the gray matter, and in extreme cases efferent impulses may be sent to all the muscles, causing contraction and resulting in convulsions. In early life diffusion of impulses occurs much more readily than in later years, which accounts for the fact that conditions which cause marked muscular contractions or convulsions in a child often cause only mild contractions or a chill in adults. In some cases light stimuli may cause marked diffusion. It is thought that: (1) certain drugs (like strychnin and caffein) affect the synapses and render the passage of impulses easier; (2) some toxins produce a state of abnormal irritability or sensitiveness; and (3) there may be a summation of mild stimuli such as the irritations due to intestinal worms.

Automatic action.—Some of the nerve centers are in a state of constant stimulation due (1) to some unknown inherent property, and (2) to substances contained in the circulating blood which are constantly acting upon them. In consequence they are constantly discharging impulses to the organs they innervate. The centers controlling respiration and the action of the heart are of this type and are described as automatic.

Inhibition.—If every stimulation were followed by its full response the body would be "on the jump" all the time. This overactivity is checked by the partial or complete blocking of impulses or their results which is known as inhibition. This is accomplished in three ways: (1) by the resistance offered to the passage of impulses at the synapses; (2) certain centers in the brain inhibit or block the flow of impulses. This may be voluntary or involuntary. The first is called self-control, though even this may become so strong a habit that it is involuntary. (3) Many of the viscera are supplied with nerves from two different sources, one set inhibiting the action of the other. We do not know how this is brought about, but it is thought to be due to some physicochemical change which the impulses cause in the effectors, and this in turn is due to some peculiarity of the end-organs or of the cells.

Fatigue of nerve cells.—Various authorities state that a normal neuron when stimulated first increases in size (due to increased metabolism), but long-continued activity decreases the size of the cell bodies, reduces the granular material of the protoplasm, and the chromatic material of the nucleus. If the fatigue is not excessive a period of rest will restore the cells to a normal

condition. It is thought that fatigue of nerve cells may be brought about in two ways, namely, by causing an accumulation of waste products, or by exhausting the reserve nutritive material of the cell. The first is known as the fatigue of depression, and the second as the fatigue of excitation. Nerve fatigue is induced by both mental and muscular work. In the former case the fatigue substances are developed in the brain, in the latter case they are developed in the reflex centers maintaining muscular activity and in the muscles themselves, they are then absorbed by the blood and carried to all parts of the nervous system.

The onset of fatigue is favored by poor health and mental conflict of any kind such as regrets, worry, fear, etc. Conscious effort to keep the attention concentrated induces fatigue more readily than when such effort is not necessary. Work done under compulsion as from a sense of duty results in fatigue more readily than when interest is the driving motive.

Constant irritation such as eyestrain, abnormal conditions of the feet, prolonged distention of the intestine with feces such as occurs in chronic constipation, in fact anything that causes pain or a continued sense of discomfort, brings about conditions in the nervous system similar to those caused by fatigue.

Shock following surgical operation is due to depression of the nerve centers which lessens the tone of the blood-vessels, thereby interfering with the circulation of the blood. This depression is caused by the inflow of impulses from the receptors in the cut tissues, and this even while the patient is under an anesthetic and not conscious of pain. The practice of injecting a local anesthetic in the area of operation is intended to inhibit the stimulation of the receptors, and the inflow of impulses to the nerve centers.

One of the results of fatigue is to increase the resistance to the passage of impulses at the synapses, and the higher cerebral centers are most easily and quickly affected. It is for this reason that young children "go stale" very quickly unless their mental training is properly balanced by rest and play.

Nerve fibers show little or no evidence of fatigue even after strenuous exercise, but the junction[6] of the motor end-plates with the muscles is readily affected.

It is often stated that change of activity is within certain

[6] Called *myo-neural junction*, from two Greek words, *Myo*, muscle, and *Neural*, nerve.

limits quite as restful as doing nothing. It is questioned whether this is true of mental activity, but it does apply to muscular activity, and the explanation offered is that when sensory stimuli are altered, new pathways and new groups of muscles are called into play. For example, a person who is tired of housework may go out of doors and walk or skate for hours, because the fresh air, changed environment, and different thoughts serve as new stimuli, travel different brain paths, and throw into activity different groups of muscles and gland cells.

Normally the fatigue of nerve tissue resulting from each day's activities is repaired by a night's sleep, but if day after day for an extended period, the fatigue is excessive, it accumulates, as it were, and a pathological condition results. This is more apt to happen if mental conflict and repressed desires add their quota. If in addition monotony—which means the same neurons are activated by the same kind of stimuli each day—is added, abnormal states variously known as brain fag, neurasthenia and nervous prostration are likely to develop. The depression of the higher cerebral centers is usually the starting point of such a condition. If the will power is weakened, the power of concentration lessened, and the higher mental capacities reduced, the imagination is likely to substitute morbid ideas and fears (phobias) that under ordinary circumstances would not be thought of, or if they were, would be rejected, or reasoned away.

Worry and fear stimulate some parts of the sympathetic system and bring about conditions in the alimentary canal that favor indigestion and constipation, two complaints that are associated with a wide range of neurasthenic conditions.

Hypersensitiveness, or excessive response to stimuli, often follows the depression of the higher inhibition capacities. Even slight stimuli may be interpreted as pain, and ordinary sounds are regarded as loud noises. It is while in this condition that an individual is susceptible to suggestion which may help him to regain his control, or on the other hand may be his undoing, for if he hears of abnormal symptoms he is likely to think he has them, and he may acquire them, for it has been proven that the vascularity and sensitiveness of a part may be increased if the attention is centered upon it. It is to this state that the advertisements of patent medicines which include long lists of symptoms that can be cured by the particular remedy advertised make their appeal, and this group of sufferers are the ready victims of many kinds of quacks.

SUMMARY

Functions of Nervous System
- Serves as means of communication between different parts of the body.
- Controls human thought and conduct.
- Gives power to perceive and appreciate world about us, to see, to move, to hear and to talk.
- Main factor in control of internal organs.
- Furnishes body knowledge of environment.

Nervous System

Classified according to location

1. Central nervous system
   - Brain
     - Cerebrum.
     - Cerebellum.
     - Mid-brain.
     - Medulla oblongata.
     - Pons Varolii.
   - Spinal cord.
2. Peripheral nervous system
   - Cranial nerves, and end-organs.
   - Spinal nerves, and end-organs.
   - Sympathetic nervous system.

Classified according to function

1. Central nervous system
   - Spinal cord.
   - Spinal nerves.
   - Brain
     - Cerebrum.
     - Cerebellum.
     - Mid-brain.
     - Medulla oblongata.
     - Pons Varolii.
   - Cranial Nerves.
2. Autonomic nervous system
   - Para-sympathetic
     - Cranial autonomic.
     - Sacral autonomic.
   - Sympathetic
     1. Centers in the cervical, thoracic and lumbar regions of the cord.
     2. Sympathetic ganglia and their fibers.
     3. The great plexuses.
   - Enteric
     - Plexuses in the walls of the alimentary canal.

Function
- Central Nervous System, or Cerebrospinal or Voluntary Nervous System, includes
  1. Parts of the brain concerned with consciousness and mental activity.
  2. Parts of the brain, cord and their nerves that control skeletal muscles.
  3. End-organs of all the sensory nerves.
- Close correlation between these two divisions.
- Autonomic System, Visceral, Splanchnic or Involuntary Nervous System includes
  - All those parts of the Nervous System which innervate
    1. All plain muscular tissue in body.
    2. The heart muscle.
    3. The glands.

Nerve tissue.—A tissue of differentiated cells called neurons held in place by neuroglia.

Neuroglia.—Consists of cells that give off processes which form a supporting network for neurons. Derived from the ectoderm.

Properties of Nerve Tissue
1. Irritability, or the power to respond to stimulation.
2. Conductivity, or the power to transmit stimuli.

Neuron Concept
- The nervous system may be reduced to a simple unit called a neuron
- The neuron may be regarded as the building stone of the nervous system.

Neuron
- **Cell body**
  - Mass of cytoplasm containing fibrils and Nissl bodies.
  - Cytoplasm surrounds nucleus which contains a nucleolus.
  - Function—source of energy and affords nutriment to its processes.
- **Cell processes**
  - Dendrites or dendrons — Usually short, break up into many branches. Rough outline—diminish in caliber. May be one, or many.
  - Axons, neuroaxons, or axis cylinder processes — May be long, smooth outline, diminishes in caliber very little. Gives off collaterals.
  - Function is conduction of nerve impulses either *to* the cell body (afferent), or *from* the cell body (efferent)

Function of Neurons
- Receive nerve impulse and convey it to other cells.
- Can conduct in only one direction, hence distinct polarity.
- Afferent, receptor sensory neurons — Carry impulses from periphery to center.
- Efferent, effector motor neurons — Carry impulses from center to periphery.
- Central connecting or internuncial neurons — Carry impulses from sensory neurons to motor neurons.

Nerve fiber
- Medullated
  - Fiber
  - Myelin sheath—function. Protects and insulates.
  - Neurilemma
- Non-medullated
  - Fiber
  - Neurilemma

Nodes of Ranvier
- Ring-like constrictions in medullated fibers, due to absence of myelin sheath.
- Minute side branches called collaterals given off from nodes.

Synapse
- Interlacing of the fine branches of the axon of one neuron, with the branches of a dendrite of another neuron. *Not* an anatomical continuation. Nerve impulses are able to bridge the microscopic gap.

End-organs
1. End arborizations—terminations in brain or cord.
2. Inter-epithelial arborizations Organules — Terminations of sensory fibers at the periphery of the body.
3. Motor end-plates—terminations of motor nerve fibers in voluntary muscle.
4. Plexus—network of non-medullated fibers in viscera.

Nerves
- Bundles of nerve fibers bound together to make funiculi.
- Funiculi bound together to make nerve trunks.
- Connective tissue surrounds funiculi and nerve trunks.

Nucleus.—A grouping of the cell bodies of several neurons within the central nervous system.

Ganglion.—A grouping of the cell bodies of several neurons within the autonomic system.

Center.—A group of neurons regulating a certain function. May be either a nucleus or a ganglion.

Classification of Nerve Tissue
- **Gray Matter**
  - Cell bodies of neurons and many of their processes.
  - Found in: Cortex of brain. Core of spinal cord. Nuclei and ganglia.
- **White Matter** — Medullated processes of cell bodies grouped together into nerves.

Reflex Concept — Nervous action of all kinds may be reduced to the reflex act. The reflex circuit forms the functional basis of all nervous activity.

Types of Reflex Circuits
- 1. Consists of two neurons
  - Receptor or sensory.
  - Effector or motor.
- 2. Consists of three neurons
  - Sensory or receptor.
  - Central.
  - Motor or effector.
- 3. Consists of complexes of above.

Classification of Reflexes
- Simple.
- Complex.
- Spreading.
- Tonic or continuous.
- Clonic or periodic.
- Association or perception.
- Antagonistic.
- Alternating.

Reflex Time
- Time elapsing between application of stimulus and automatic response.
- Depends upon
  - 1. Strength of the stimulus.
  - 2. Nature of stimulus.
  - 3. Number of relay stations through which impulses are transmitted.

Nature and Speed of Nerve Impulses
- Not positively known.
- Thought to be of a physico-chemical nature.
- Identical in character, vary only in intensity.
- 120 meters (393 feet) per second.

Nerve-endings
- Not all affected by the same stimuli.
- Special end-organs to mediate each sense.

Summation of Stimuli
- Subminimal stimuli—too slight to produce response.
- Succession of subminimal stimuli renders nerve cell more sensitive—this is described as summation.

Bahnung or Facilitation — Term applied to lessened resistance in nerve pathway that is frequently used.

Diffusion of Impulses
- Incoming nerve impulses have many nerve paths open to them.
- Resistance offered at synapses and pathways limits diffusion.
- Very strong stimulus may overcome resistance—efferent impulses sent to all muscles, thus producing convulsions.
- Summation of stimuli may produce similar effect.

Automatic Action
- Some of the nerve centers are in state of constant stimulation.
- Due to
  - Some unknown inherent property.
  - Substances in the blood, which act upon them.

Inhibition
- Partial or complete blocking of impulses or their results.
- Accomplished by
  - Resistance offered at synapses.
  - Voluntary or involuntary blocking in nerve centers.
  - Antagonistic action of nerves from two sources.

Fatigue of Nerve Cells
- When first stimulated neurons increase in size.
- Long-continued Activity
  - Decreases size of cell bodies.
  - Reduces granular material of cytoplasm.
  - Reduces chromatin of nucleus.
- Varieties
  - Fatigue of depression—due to accumulation of waste products.
  - Fatigue of excitation—due to exhausting nutritive material of cell.

Fatigue of Nerve Cells	Due to	Mental and Muscular Work	Fatigue substances developed in brain, in reflex centers and muscles carried by blood to all parts of the nervous system.
			Poor health, mental conflicts, efforts at concentration, favor onset.
	Results		Resistance at synapses increased.
			Junction of motor end-plates with muscles effected.

CHAPTER VIII

THE NERVOUS SYSTEM, CONTINUED.—THE SPINAL CORD AND SPINAL NERVES; THE BRAIN AND CRANIAL NERVES; THE AUTONOMIC SYSTEM

A brief sketch of the lower animals characterized as segmental, is helpful in understanding the structure and functions of the spinal cord. Segmental animals are made up of a number of smaller units which are capable of leading an independent existence. This is made possible by the fact that each segment possesses separate circulatory, digestive, excretory, and nervous systems, so that the segments may be separated without endangering or seriously impairing their life processes. As far as the nervous system is concerned, we find that each segment of these animals is equipped with a centrally-placed ganglion from which nerve fibers extend in all directions to the different tissues of this segment. A stimulus applied to its surface is soon followed by movement or some other motor response. It appears, therefore, that the nervous elements allotted to each segment are arranged in the form of reflex circuits, their centers being grouped in the shape of a central ganglion. The life of the animal as a whole, however, requires a certain *correlation* between the activities of its different segments and a *subordination* of the latter to the functional necessities of the whole. This end is attained first by intermediary neurons which unite the successive ganglia with one another and secondly, by a hyperdevelopment of the head-ganglion which thus gains a directing control over the others.

A nervous system of this kind is reflex in its nature and forms the basal stem around which the nervous system as it appears in the highest animals is eventually developed. The head-ganglion is comparable to the brain, the segmental ganglia to the spinal cord, and from these parts the afferent and efferent nerves arise.

The spinal cord is that portion of the nervous system lodged within the spinal canal of the vertebral column. It consists of a collection of gray and white substance, extending from the foramen magnum of the skull, where it is continuous with the medulla oblongata, to about the second lumbar vertebra, where it tapers off into a fine thread called the *filum terminale*. Before its

termination it gives off a number of fibers which form a tail-like expansion, called the *cauda equina*. (See Fig. 92.) It diminishes slightly in size from above downward, with the exception of presenting two enlargements in the cervical and lumbar regions, where the nerves are given off to the arms and legs respectively. Its average length is about 18 inches (45 cm.) The spinal cord is incompletely divided into lateral halves by a ventral[1] and dorsal fissure; the ventral fissure dividing it in the middle line in front, and the dorsal fissure in the middle line behind. Because of these fissures, only a narrow bridge of the substance of the cord connects its two halves. This bridge, called the transverse commissure is traversed throughout its entire length by a minute *central canal*, which opens into the fourth ventricle at its upper end, and at its lower terminates blindly in the filum terminale.

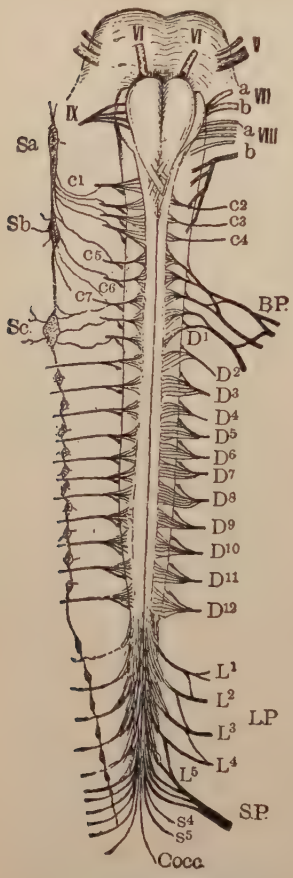


FIG. 101.—VENTRAL VIEW OF BASE OF BRAIN, SPINAL CORD, AND SPINAL NERVES. On the left hand side, the sympathetic chain of ganglia is shown. *Sa*, *Sb*, *Sc*, superior, middle and inferior cervical ganglia, *V-IX*, cranial nerves. C^1-C^7, D^1-D^{12}, L^1-L^5, S^4, S^5 and Cocc., spinal nerves, seen emerging from spinal cord by two roots. *B.P.*, brachial plexus. *L.P.*, lumber plexus. *S.P.*, sacral plexus.

Meninges or membranes.—The spinal cord does not fit closely into the spinal canal, as the brain does in the cranial cavity, but is suspended within it. It is protected and nourished by three membranes which are continuous with the membranes covering the brain and are called by the same names, *viz.*, the pia mater, closely investing the cord, the arachnoid, and the dura mater outside.

Structure of the cord.—The cord consists of gray and white matter. The gray matter consists of nerve cells and nerve fibers held together by neuroglia. The white matter consists of nerve fibers embedded in a network

[1] As stated on page 6, the terms ventral and dorsal are used for front and back aspects of the body.

of neuroglia. The gray and white matter are supported by connective tissue, and supplied with blood-vessels and lymph-vessels.

The *gray matter* is in the interior surrounding the central canal and on cross-section appears to be arranged in the form of the letter H. The transverse bar of the H is called the gray commissure, and connects the two lateral masses of gray matter. On each side the gray matter presents a ventral, and a dorsal horn. The former is short and bulky while the latter is long and slender. The ventral horn contains the cell bodies from which the efferent (motor) fibers of the spinal nerves arise. These pass out through openings in the meninges and the inter-

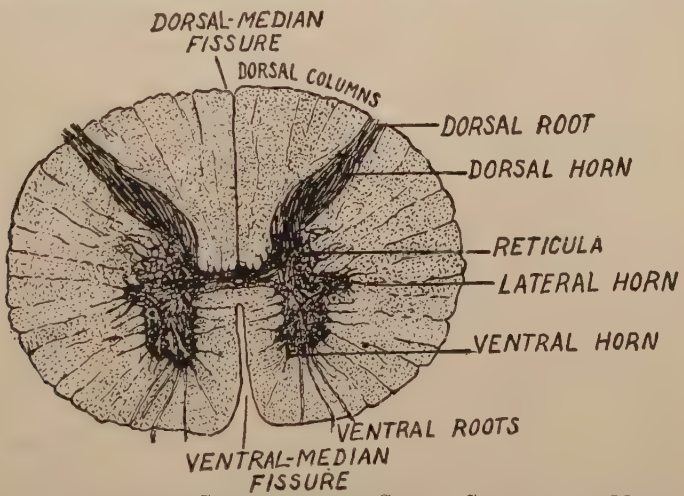


FIG. 102.—TRANSVERSE SECTION OF THE SPINAL CORD AT THE MIDDLE OF THE THORACIC REGION. (Gerrish.)

vertebral foramina. The ventral horn also contains ganglia which give rise to the efferent fibers of the white *rami communicantes*[2] (See Fig. 112) or preganglionic fibers, which connect with the sympathetic ganglia outside the vertebral column. The dorsal horn contains the cell bodies from which the ascending and afferent fibers that go up to the brain arise. The afferent fibers of the spinal nerves entering the cord form synapses with the neurons in these horns. The gray matter also contains a great number of central or connecting neurons which serve for the pas-

[2] See page 163. Preganglionic fibers are efferent, medullated fibers (white rami) which pass from the spinal cord by way of the ventral horn, and end by arborizing around the cells of a sympathetic ganglion. From the cells of the ganglia, postganglionic fibers go to the various effector organs, *i.e.*, smooth muscle, cardiac muscle and glands. The latter are non-medullated. Some pass back to the spinal nerves and form the gray rami.

sage of impulses (1) from the dorsal (afferent) to the ventral (efferent) roots of the spinal nerves, (2) from one side of the cord to the other, (3) from one level of the cord to another.

The *white matter* is arranged around and between the horns of gray matter, the proportion of gray and white varying in different regions of the cord. On each side the white matter may be said to consist of three portions or funiculi, namely, a ventral, a lateral, and a dorsal. Each funiculus is in turn divided into smaller segments or fasciculi, commonly called columns or tracts.

Some of these columns consist of fasciculi made up of fibers which are ascending or sensory. They serve as pathways to the brain for impulses entering the cord over afferent fibers of spinal nerves. They begin in the gray matter of the cord, ascend and terminate in the gray matter of the brain, *e.g.*, 1, 2, 4, 5, in Fig. 103. Other columns consist of fasciculi which are descending or motor. They transfer impulses from the brain to the motor neurons of the spinal nerves. They begin in the gray matter of the brain, descend and terminate in the gray matter of the cord, *e.g.*, 3 and 6. Other columns (white in Fig. 103) are made up chiefly of short ascending and descending fibers beginning in one region of the spinal cord and ending in another.

The columns in the dorsal portion are chiefly ascending. Injury to these columns will interfere with the passage of afferent impulses and possibly (depending on location and extent of injury) loss of sensation in the parts from which the passage of impulses is blocked. Locomotor ataxia or tabes dorsalis is a degeneration of the dorsal columns and dorsal horns of the cord, resulting in disturbances of sensation, interference with reflexes and consequently with movements such as walking, which after it is once learned is largely reflex. Anterior poliomyelitis, or infantile paralysis, is inflammation of the ventral areas of gray matter and results in paralysis of the parts supplied with motor nerves from the diseased portion of cord.

Functions of the spinal cord:—

(*a*) It is an important center of reflex action.

(*b*) It consists of the principal conducting paths to and from the higher centers.

From the standpoint of function the spinal cord may be regarded as consisting of more or less independent segments. Each segment is related by afferent and efferent nerve fibers to a definite area of the body.

SPINAL NERVES

There are thirty-one pairs of spinal nerves, arranged in the following groups, and named for the region of the vertebral column from which they emerge:

Cervical	8 pairs
Thoracic	12 pairs
Lumbar	5 pairs
Sacral	5 pairs
Coccygeal	1 pair

The first cervical nerve arises from the medulla oblongata and leaves the neural canal between the occipital bone and the atlas. With this one exception the spinal nerves spring from both sides of the spinal cord, and all except the coccygeal pass out through the intervertebral foramina. The coccygeal passes from the lower extremity of the canal.

Mixed nerves.—The spinal nerves consist almost entirely of medullated nerve fibers, and are called mixed nerves because they contain both sensory and motor fibers. Each spinal nerve has

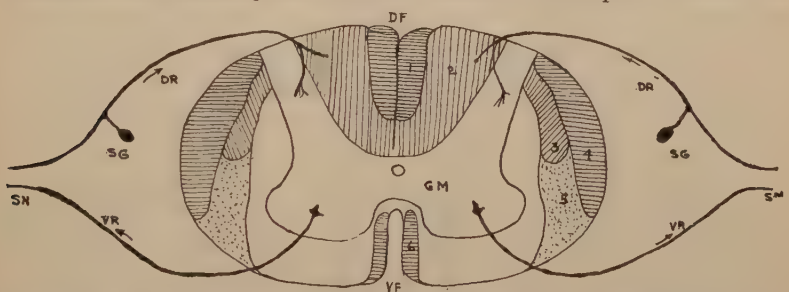


FIG. 103.—CONDUCTION PATHS IN SPINAL CORD. 1, 2, fasciculi in dorsal funiculus; 6, fasciculus in ventral funiculus. *D.F.*, dorsal fissure; *D.R.*, dorsal root; *G.M.*, gray matter; *S.G.*, spinal ganglion; *S.N.*, spinal nerve; *V.F.*, ventral fissure; *V.R.*, ventral root. 1 Column of Goll; 2 Column of Burdach; 3 crossed pyramidal tract; 4 Flechsig's tract; 5 Gower's tract; 6, direct pyramidal tract.

two roots, a ventral root and a dorsal root. The fibers of the ventral root arise from the gray matter in the ventral horn, and are direct prolongations from the cell bodies, consequently they are efferent fibers and convey impulses from the spinal cord to the periphery.

The fibers of the dorsal root arise from the cells composing the enlargement or ganglion of the dorsal root situated in the openings between the arches of the vertebræ. These cell bodies give off a single fiber which divides in a *T* shaped manner into two processes, one extends to a sensory end-organ of the skin, or

muscle, or tendon, or joint or viscera. The other extends into the spinal cord in the dorsal root of a spinal nerve.

The fibers that enter the cord directly do not all pass into the gray matter immediately, some extend upward and some downward before doing so. Sooner or later they all enter the gray matter of the spinal cord or medulla, where they form synapses with central or motor neurons.

It should be borne in mind that the ventral roots have their origin within the spinal cord and contain only motor fibers which are *efferent*. The dorsal roots have their origin outside of the cord, *i.e.*, in the spinal ganglia, and contain only sensory fibers,

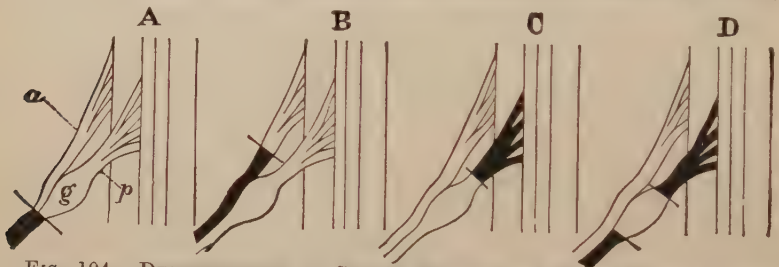


FIG. 104.—DEGENERATION OF SPINAL NERVES AND NERVE ROOTS AFTER SECTION. *A*, section of nerve trunk beyond the ganglion; *B*, section of ventral root *C*, section of dorsal root; *D*, excision of ganglion; *a*, ventral root; *p*, dorsal root; *g*, ganglion. Black indicates the portion of the nerve which degenerates after section.

which are *afferent*. The fibers connected with these two roots are collected into one bundle, and form a spinal nerve trunk just before leaving the canal through the intervertebral openings.[3]

Distribution of the terminal branches of the spinal nerves.—After leaving the spinal cord each spinal nerve divides into two main trunks known as the ventral and dorsal divisions. Each of these contains sensory and motor fibers. The ventral division supplies the extremities and parts of the body in front of the spine. The dorsal division supplies the muscles and skin of the back of the head, neck, and trunk. Each ventral division connects with the sympathetic ganglia by means of fibers which pass from the nerve to the sympathetic ganglia and *vice versa*. Previous to their final distribution in the cervical, sacral, and lumbar regions these nerves form plexuses known as the cervical, sacral, and lumbar plexuses. In passing to the viscera, muscles, skin, etc., these terminal nerves follow the same pathway as the blood-vessels. (See Fig. 101.)

[3] The relations of the roots, fibers, and so forth, can best be understood from a study of Figs. 103 and 104.

Names of peripheral nerves.—Many of the larger branches given off from the spinal nerves bear the same name as the artery which they accompany, or the part which they supply. Thus the radial nerve passes down the radial side of the forearm in company with the radial artery; the intercostal nerves pass between the ribs in company with the intercostal arteries. An exception to this is the two sciatic nerves which pass down from the sacral plexus, one on either side of the body near the center of each buttock, and the back of each thigh, to the popliteal region where each divides into two large branches which supply the leg and foot. Motor branches from these nerves pass to nearly all the muscles of the legs and feet and they receive sensory branches from nearly all parts of the skin of the lower extremities.

Degeneration and regeneration of nerves.—Since the cell body is essential for the nutrition of the whole cell, it follows that if the processes of a neuron are cut off, they will suffer from malnutrition and die. If, for instance, a spinal nerve be cut, all the peripheral part will die, since the fibers composing it have been cut off from their cell bodies situated in the cord, or in the spinal ganglia. The divided ends of a nerve that has been cut across readily reunite by cicatricial tissue,—that is to say, the connective tissue framework unites, but the cut ends of the fibers themselves do not unite. On the contrary, the peripheral or severed portion of the nerve begins to degenerate, the medullary sheath breaks up into a mass of fatty molecules and is gradually absorbed, and finally the central fiber also disappears. In regeneration, the new fibers grow from the central end of the severed nerve trunk, and penetrating into the peripheral end of the neurilemma, grow along this as the fiber of the new nerve, each fiber after a time becoming surrounded with a medullary sheath. Restoration of function in the nerve may not occur for several months, during which time it is presumed the new nerve fibers are slowly finding their way along the course of those which have been destroyed.

THE BRAIN

The brain is the largest and most complex mass of nervous tissue in the body. It is contained in the cavity formed by the bones of the cranium, and comprises five fairly distinct, though connected parts: the cerebrum, the cerebellum, the mid-brain, the medulla oblongata, and the pons Varolii.

In early embryonic life the brain consists of three hollow vesicles named, the fore-brain or prosencephalon, the mid-brain

or mesencephalon, and the hind-brain or the rhombencephalon. During growth the cerebral hemispheres, their commissures, the first, second and third ventricles are developed from the fore-brain; the corpora quadrigemina, the cerebral peduncles and the

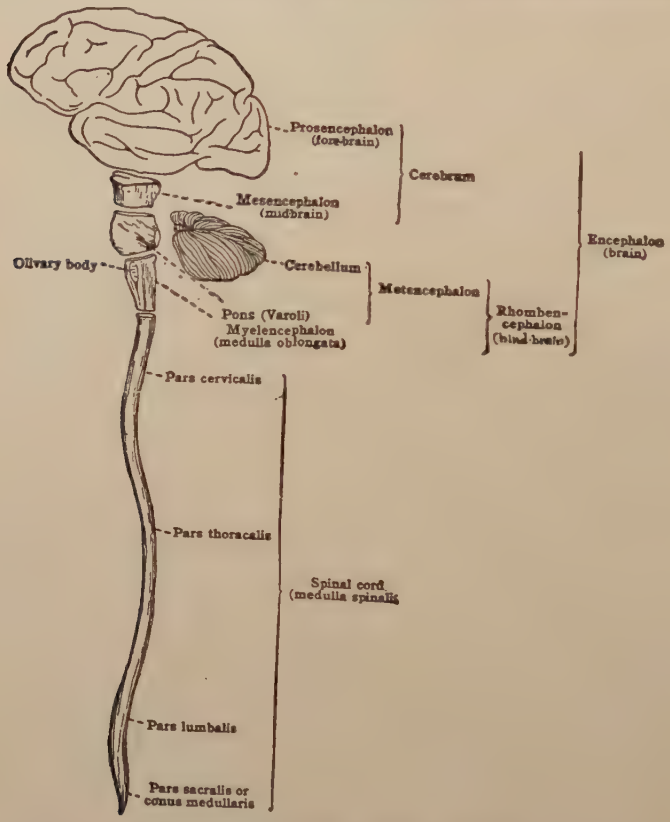


FIG. 105.—DIAGRAM ILLUSTRATING THE GROSS DIVISIONS OF THE CENTRAL NERVOUS SYSTEM. To some authors the word mesencephalon refers to that part of the embryonic brain which develops into the cerebellum. To others it refers to the hind-brain. Morris' Anatomy. (Published by Blakiston.)

cerebral aqueduct (a tubular connection between the third and fourth ventricles) are developed from the mid-brain; the medulla oblongata, the pons Varolii, the cerebellum and the included fourth ventricle are developed from the hind-brain.

Weight of the brain.—The average weight of the brain in the adult male is about 48.6 ounces (about 1380 gms.); in the adult female, about 44 ounces (about 1250 gms.). The weight of the brain is an indication of growth, which in early life depends upon

an increase in the number of cells and their processes. Later it depends on the growth of the cells and their processes. The brain grows rapidly up to the fifth year and ceases to grow generally in the eighteenth or twentieth year. As age advances the brain loses weight, at first slowly, later more rapidly.

Development of the brain.—The development of the brain is not entirely a matter of growth but rather a matter of forming new pathways, *i.e.*, new connections between synapses, and a permanent modification of the synapses that are functionally active during various forms of mental activity. The nature of

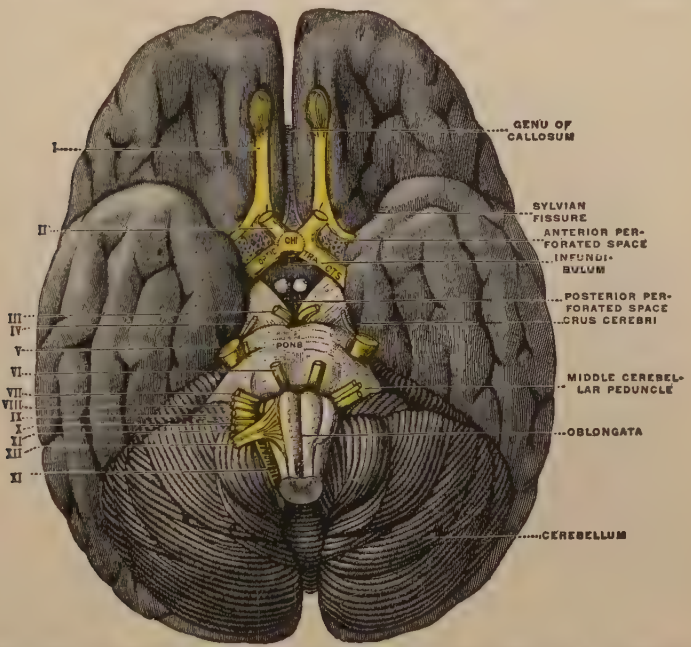


FIG. 106.—UNDER SURFACE OF THE BRAIN, SHOWING THE SUPERFICIAL ORIGINS OF THE CRANIAL NERVES. The Roman numerals indicate the nerves. (Gerrish.)

the brain protoplasm, and the use to which it is put determines to some extent the length of time during which development may continue. Mental exercise keeps the brain active and capable of development just as exercising a muscle tends to prevent atrophy, or loss of function.

Cerebrum.—The cerebrum is by far the largest part of the brain. It is egg-shaped, or ovoidal, and fills the whole of the upper portion of the skull. The entire surface, both upper and under, is composed of layers of gray matter, and is called the

cortex because, like the bark of a tree, it is on the outside. The bulk of the white matter in the interior of the cerebrum consists of very small fibers running in three principal directions: (1) from above downward, (2) from the front backward, and (3) from side to side. The fibers link the different parts of the brain together, and connect the brain with the spinal cord.

Fissures and convolutions.—In early life the cortex of the cerebrum is comparatively smooth, but as time passes and the brain develops, the surface becomes covered with furrows which vary in depth. The deeper furrows are called *fissures*, the more shallow ones, *sulci*, and the ridges between the sulci are

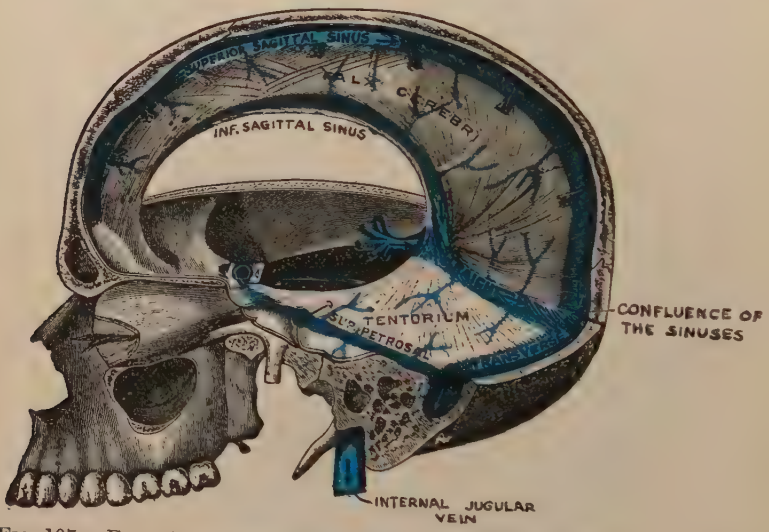


FIG. 107.—FALX CEREBRI AND TENTORIUM, LEFT LATERAL VIEW. (Gerrish.)

called gyri or *convolutions*. The fissures and sulci are infoldings of gray matter, consequently the more numerous and deeper they are, the greater is the amount of gray matter. The number and depth of these fissures and sulci is thought to bear a close relation to intellectual power; babies and idiots have few and shallow furrows, while the brains of men of intellect are always markedly convoluted. There are five important fissures which are always present. They are the following:—

(1) The *Longitudinal Cerebral Fissure*, which extends from the back to the front of the cerebrum, and almost completely divides it into two hemispheres, the two halves, however, being connected in the center by a broad, transverse band of white fibers called

the *corpus callosum*. A process of the dura mater extends down into this fissure and separates the two cerebral hemispheres. It is called the *falx cerebri*, because it is narrow in front, and broader behind, thus resembling a sickle in shape. Blood is returned from the brain in venous channels called sinuses. Two important sinuses are lodged between the layers of the falx cerebri. The superior sagittal sinus is contained in the upper border, and the inferior longitudinal sinus in the lower border. Fig. 107 shows these two sinuses, also the *straight sinus*, the *transverse* or *lateral*, and the *superior petrosal* sinuses of one side of the head. *Confluence of sinuses* (torcular Herophili) is the term applied to the dilated extremity of the superior sagittal sinus.

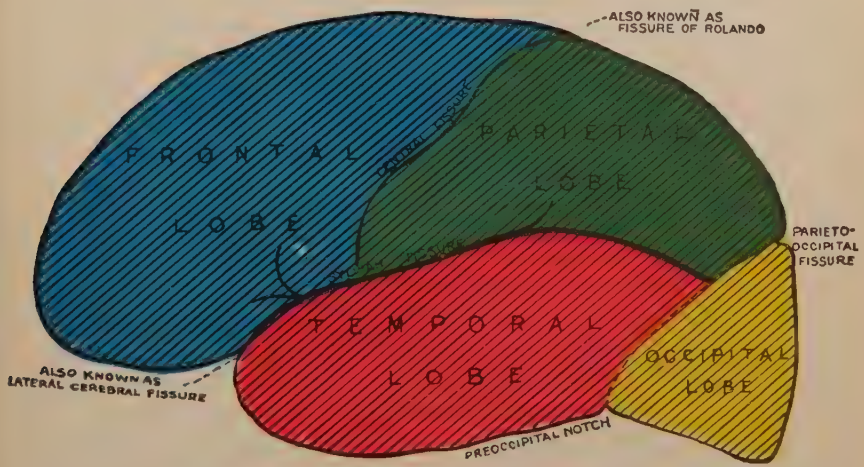


FIG. 108.—THE LOBES OF THE CONVEX SURFACE OF THE HEMISPHERE, LEFT SIDE. (Gerrish.)

(2) The *Transverse Fissure*, which is between the cerebrum and the cerebellum. A process of the dura also extends into this fissure, and covers the upper surface of the cerebellum and the under surface of the cerebrum. It is called the *tentorium cerebelli*.

(3) *Fissure of Rolando, or* central sulcus
(4) *Fissure of Sylvius* (lateral cerebral fissure)
(5) *Parieto-occipital fissure*

There is one of each in each hemisphere. For location see Fig. 108.

Lobes of the cerebrum.—The longitudinal fissure divides the cerebrum into two hemispheres, and the transverse fissure divides the cerebrum from the cerebellum. The three remaining fissures assisted by certain arbitrary lines divide each hemisphere into

five lobes. With one exception these lobes were named from the bones of the cranium under which they lie; hence they are known as:—(1) **Frontal lobe.** (2) **Parietal lobe.** (3) **Temporal lobe.** (4) **Occipital lobe.** (5) **The Insula (Island of Reil).**

(1) The **frontal** lobe is that portion of the cerebrum lying in front of the fissure of Rolando, and usually consists of four main convolutions.

(2) The **parietal** lobe is bounded in front by the fissure of Rolando, and behind by the parieto-occipital fissure.

(3) The **temporal** lobe lies below the fissure of Sylvius (lateral cerebral fissure) and in front of the occipital lobe.

(4) The **occipital** lobe occupies the posterior extremity of the cerebral hemisphere. When one examines the external surface of the hemisphere, there is no marked separation of the occipital lobe from the parietal and temporal lobes that lie to the front; but when the surface of the longitudinal cleft is examined, the parieto-occipital fissure serves as a boundary anteriorly for the occipital lobe.

(5) The **Insula** (Island of Reil) is not seen when the surface of the hemisphere is examined, for it lies within the fissure of Sylvius, and the overlying convolutions of the parietal and frontal lobes must be lifted up before the Insula comes into view.

Ventricles of the brain.—The brain is not a solid mass, but contains cavities called ventricles. The two lateral ventricles are situated one in each of the cerebral hemispheres under the mass of white fibers called the corpus callosum,[4] which connects the two hemispheres. The basal ganglia of the brain are in the floor of the lateral ventricles. The third ventricle is behind the lateral ventricles but connected with each one by means of small openings called the foramina of Monro. The fourth is in the medulla oblongata in front of the cerebellum and behind the pons Varolii. It is an expanded continuation of the central canal of the spinal cord. The third communicates with the fourth by means of a slender canal called the aqueduct of the cerebrum (aqueduct of Sylvius). In the roof of the fourth ventricle are three openings, the median one being called the foramen of Magendie. By means of these three openings, the ventricles communicate with the subarachnoid[5] cavity, and the cerebrospinal fluid can circulate from one to the other. The fourth ventricle may be called an expansion of the central canal of the spinal cord, so that the cerebrospinal fluid can cir-

[4] See page 147. [5] See page 156.

culate from the ventricles to the central canal[6] of the spinal cord. The so-called fifth ventricle is not a portion of the general cavity —not a true ventricle. It is a narrow space in front of the third having no connection with the other ventricles. The cavity of the lateral ventricles is large enough to occupy an appreciable space, and may become over-distended with cerebrospinal fluid in certain conditions of disease.

Functions of cerebrum.—In the higher vertebrates the cerebrum constitutes a larger proportion of the central nervous system than in the lower forms. It is especially large in animals that are capable of profiting by experience, hence has come to be

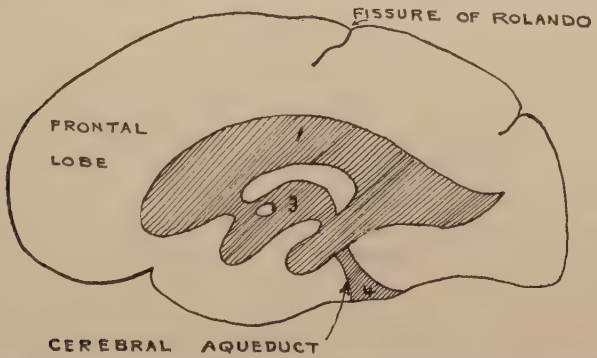


FIG. 109.—DIAGRAM TO SHOW THE VENTRICLES OF THE BRAIN IN POSITION. 1, lateral or first ventricle, of which there are two, one in each cerebral hemisphere; 3, third ventricle, and 4, beginning of fourth ventricle.

regarded as the organ of *associative memory*. The nerve centers which govern all our mental activities, reason, intelligence, will, memory, and the higher emotions and feelings, are located in the cerebrum. It is the seat of consciousness, the interpreter of sensations, the instigator of voluntary acts, and exerts a controlling force (both accelerating and inhibiting) upon many reflex acts which originate as involuntary. Laughing, weeping, micturition, defecation and many other acts might be cited as examples of the latter.

Localization of brain function.—As the result of numerous experiments on animals, and close observation of individuals suffering from wounds or cerebral disease, physiologists have been able to localize certain areas in the brain which control motor and sensory activity. They have also been able to gain some knowledge of the areas in the cerebrum which are concerned with the higher mental activities. But in no case is the

[6] See page 138.

control of a function limited to a single center, for practically all mental processes involve the discharge of nervous energy from one center to another, and the recall of memories of former experiences. The latter is called associative memory.

Names of areas.—That portion of the cerebrum which governs muscular movement is known as the *motor area*, the portions controlling sensation as the *sensory areas*, and those connected with the higher faculties, such as reason and will, as *association areas*.

Motor areas.—The surface of the brain assigned to the function of motion is the posterior part of the frontal lobe, *i.e.*, the

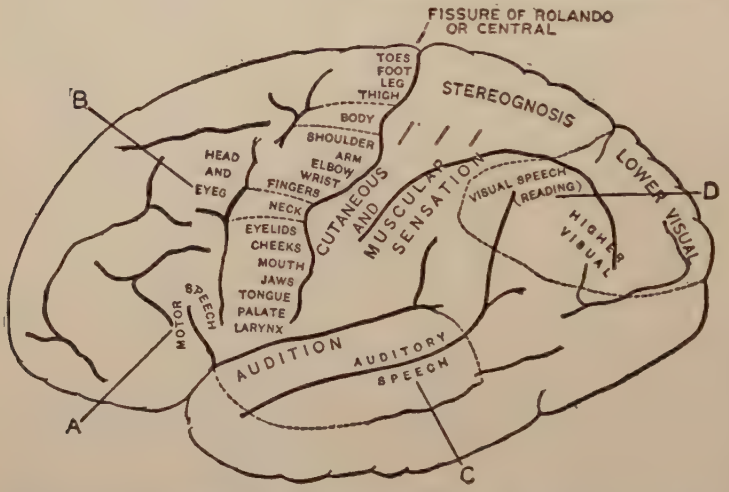


Fig. 110.—Localization of Function in the Cerebral Cortex. (Adapted from Woolsey's "Surgical Anatomy.") The cortical area marked *A* is the motor speech center, damage to which causes loss of the word-forming power (motor aphasia). Damage to the cortical area marked *B* abolishes the power of writing, a form of sensory aphasia called agraphia. Damage to the center marked *C* produces word-deafness (sensory aphasia). Damage to the cortical area marked *D* produces word-blindness (sensory aphasia). Stereognosis means the ability to recognize the form of objects by the sense of touch.

gray matter immediately in front of the fissure of Rolando. The centers which govern skeletal muscles are controlled by nerves arising in this area, and the special portions of the area in which the nerves supplying the various parts arise, for example, tongue, mouth, fingers, leg, can be studied in Fig. 110. Correct diagnosis and localization of brain injuries or disease, are greatly aided by knowledge of the location of these areas, *e.g.*, a bullet wound in the head causes paralysis of the left leg, the location of the bullet in the right cerebral cortex is indicated.

Sensory areas.—The term *sensory areas* is used to designate those parts of the brain to which sensation is due, and which control vision, hearing, smell, taste, and to some extent, speech. The visual area is situated in the posterior part of the occipital lobe; the auditory area in the superior part of the temporal lobe; and the olfactory and gustatory areas are in the anterior part of the temporal lobe.

Location of speech areas.—There are four small areas in the cerebral cortex, marked A, B, C, D, in Fig. 110 which are known as the speech centers. They do not develop in both hemispheres. In right-handed persons they become fully developed in the left hemisphere, and in left-handed persons in the right hemisphere. The basis of language is a series of memory pictures. The mind must know and recall the names of things in order to mention them; it must have seen or heard things in order to describe them and to have learned the words to express these ideas. Even this is not enough. All these factors must work together under the influence of the center for articulate speech, which as seen in Fig. 110, is in close connection with those for the larynx, tongue and the muscles of the face. Injury to these centers results in some form of inability to speak,[7] to write,[8] or to understand spoken[9] or written[10] words. It is customary, therefore, to distinguish two types of aphasia, *i.e.*, motor and sensory. By motor aphasia is meant the condition of those who are unable to speak although there is no paralysis of the muscles of articulation. By sensory aphasia is meant the condition of those who are unable to understand written, printed, or spoken symbols of words, although the sense of vision and of hearing is unimpaired. These centers are really memory centers and aphasia is due to loss of memory either of words, or the meaning of words seen or heard, or of how to form letters.

Association areas.—The motor and sense areas form, so to speak, small islands which are surrounded on all sides by cerebral tissue in which as yet no definite functions have been localized. These regions are designated as association areas and are made up of association fibers which connect motor and sensory areas. Animals that are capable of acquiring habits and conditioned reflexes have a greater development of these areas. It is thought that the association areas are plastic and register the effects of individual experience.

In the absence of this organ, any animal must cease to be an

[7] Aphasia. [8] Agraphia. [9] Word-deafness. [10] Word-blindness.

association animal and must become a reflex animal. In other words, all its actions are then removed from volition, in fact, from consciousness. All responses that depend upon memory of acquired and inherited experience have been destroyed.

Cerebellum.—The cerebellum occupies the lower and back part of the skull cavity. It is below the posterior portion of the cerebrum from which it is separated by the tentorium cerebelli, a fold of the dura mater and behind the pons and the upper part of the medulla. It is oval in form, constricted in the center and flattened from above downward. The constricted central portion is called the *vermis*, and the lateral expanded portions are called the hemispheres.

The surface of the cerebellum consists of gray matter and is not convoluted but is traversed by numerous furrows or sulci. The gray matter contains cells from which fibers pass and with which fibers entering the cerebellum from other parts of the brain form synapses. The cerebellum is connected with the cerebrum by the superior peduncles, with the pons by the middle peduncles, and with the medulla oblongata by the inferior peduncles. These peduncles are bundles of fibers. Incoming impulses from the motor centers in the cerebrum, from the semi-circular[11] canals of the inner ear, and from the muscles, enter the cerebellum by way of these bundles. Outgoing impulses are transmitted to the motor centers in the cerebrum, down the cord, and thence to the muscles.

Function of cerebellum.—It is thought that the cerebellum assists in maintaining muscular tone, and is probably the chief center for the control of muscular coördination, and the maintenance of equilibrium. It is comparatively large in fishes and birds, animals that must maintain an equilibrium in three dimensional spaces. In man, injury to the cerebellum results in muscular weakness, loss of tone, and inability to direct the movements of the skeletal muscles. There may be difficulty in walking due to inability to control the muscles of the legs, or difficulty in talking due to lack of coördination of the muscles moving the tongue and jaw. The area of the body affected is determined by the location and extent of the injury to the cerebrum. Only parts of the body on the same side as the injury to the cerebellum are involved, unless both sides of the cerebellum are injured, and then the lack of muscle tone and coördination may be so great that the person is helpless.

[11] See page 473.

The mid-brain.—The mid-brain (see Fig. 105) is a short constricted portion which connects the pons and cerebellum with the hemispheres of the cerebrum. It is directed upward and forward and consists of: (1) a pair of cylindrical bodies called the cerebral peduncles, (2) four rounded eminences called the corpora quadrigemina, and (3) an intervening passage or tunnel, the cerebral aqueduct (aqueduct of Sylvius) which serves as a communication between the third and fourth ventricle. The cerebral peduncles are bundles of nerve fibers situated at the base of the brain and largely hidden by the temporal lobes of the cerebrum. They emerge from the upper surface of the pons, pass upward and forward, and disappear into the substance of the cerebral hemispheres. The corpora quadrigemina are four bodies consisting chiefly of gray matter, situated two on each side of the median line behind the peduncles.

The medulla oblongata.—The medulla oblongata (spinal bulb) is continuous with the spinal cord which on passing into the cranial cavity through the foramen magnum, widens into a pyramidal-shaped mass, with the broad end directed upward toward the pons Varolii. It is about one and one-quarter inches (3 cm.) long, and one-half inch (1.25 cm.) thick. The central canal of the spinal cord is prolonged into its lower half, and then opens into the cavity of the fourth ventricle. The arrangement of gray and white matter is much more complex than in the spinal cord. Nearly all of the medulla contains a scattering of gray matter. Immediately under the floor of the fourth ventricle aggregations of gray matter are found and contain: (1) the roots of fibers which pass to the cerebellum and cerebrum; (2) the roots of the cranial nerves from the seventh to the twelfth inclusive; (3) the roots of fibers that transmit impulses to the portions of the autonomic system which, (*a*) stimulate the heart action, and (*b*) cause the contraction of the blood-vessels; (4) the roots of the fibers that pass down the cord, connect with spinal nerves and transfer their impulses to the diaphragm and chest muscles concerned with respiration. Many afferent fibers coming up the cord form synapses with neurons in this gray matter.

Functions of the medulla oblongata.—The medulla is a connecting bridge and comes nearer to being the general crossing place of all conducting paths than any other part of the nervous system. Impulses of most of the cranial nerves must enter or leave the central nervous system by way of the medulla. Nearly

all the impulses connected with voluntary movements pass through the medulla. Impulses from one division of the central nervous system to another cross in the medulla. The fibers extending from the brain into the cord, and from the cord into the brain, decussate or cross in the medulla. Because of this it follows that the nerves arising in the cortex of the right side govern the movements of the left side of the body and *vice versa*.

In many cases of paralysis or convulsions, it is possible to locate the exact portion of the brain that is affected by close observation of the part of the body involved in the loss of function or convulsion.

In addition to its conducting paths the medulla is the seat of vital and reflex centers.

One center in the medulla, the **respiratory center** is classed as automatic. It regulates the function of respiration. Impulses which are delivered by numerous motor neurons to the muscles which contract in breathing movements originate here. The stimulus which locally excites this center is the carbon dioxide content of the blood. It is also subject to reflex and voluntary efforts which may increase or inhibit the rate of discharge of impulses temporarily.

Another important center located in the medulla is the **vasomotor center,** more accurately called the **vasoconstrictor center,** because stimulation causes contraction of the muscles in the walls of the blood-vessels. Its effect on the arteries is marked, and it functions in maintaining normal blood pressure. This center is not automatic, but is constantly stimulated by sensory impulses. Inhibition of this center causes vasodilatation, or a partial loss of tone in the arteries. In blushing the vasoconstrictor center is partially inhibited and the arteries supplying the face and neck dilate. This center is not under voluntary control. It is assumed that a nervous center for vasodilator nerves exists, though vasodilator nerves are not widely distributed.

A third vital center is **the cardiac inhibitory center.** The fibers of this center arise in the nucleus of the vagus and follow the pathway of this nerve to the heart. When they reach the heart they enter into relation with the cardiac plexus which envelops the ascending portion and arch of the aorta, and from here are distributed to the nerve centers in the heart as well as to the musculature. It is believed that this center does not cease its activity at any time but constantly discharges impulses which tend to hold the heart action in check. The activity of the heart is also

affected by nerve impulses from the cardiac sympathetic nerves. It is assumed that there are two kinds of fibers in these nerves, one the **accelerator** fibers increase the rate of the heart, the other **augmentor** fibers increase the force of the contractions. Thus two antagonistic mechanisms, the inhibiting and the accelerating act upon the heart, and the resulting heart rate is determined by the relative strength of these two stimuli.

The term **reflex centers is applied to that part of a reflex** circuit which is essential for the reflex act. Various afferent fibers converge at the center and from there on use the same final path.

The reflex centers are (1) for sneezing, (2) for mastication, (3) for deglutition, (4) for sucking, (5) for coughing, (6) for vomiting, (7) for winking, (8) for reflex secretion of saliva, and (9) for reflex secretion of gastric fluid.

All of these centers except those for the secretion of saliva and gastric fluid are stimulated by impulses transmitted by the afferent fibers of the cranial nerves supplying the parts engaged in the activities listed, and discharge impulses by the efferent fibers of these same nerves. The impulses from the seventh center pass over the secretory fibers of the vagus nerve to the salivary glands and stomach.

The Pons.—The pons (Varolii) is situated in front of the cerebellum between the mid-brain and the medulla oblongata. It consists of interlaced transverse and longitudinal white nerve fibers intermixed with gray matter. The transverse fibers are those derived from the middle peduncles of the cerebellum and, serve to join its two halves. The longitudinal fibers join the medulla with the cerebrum.

Function of pons Varolii.—The pons is a bridge of union between the two halves of the cerebellum and a bridge between the medulla and the cerebrum. It is also a place of exit for the fifth (trigeminal), sixth (abducent), seventh (facial), and eighth (acoustic) cranial nerves.

Meninges.—The brain and spinal cord are enclosed within three membranes. These are named from without inward: the dura mater, arachnoid and pia mater.

The **dura mater** is a dense membrane of fibrous connective tissue containing a great many blood-vessels. The cranial and spinal portions of the dura mater differ, and will be described separately, but it must be understood that they form one complete membrane. The cranial dura mater is arranged in two layers and the layers are attached except in a few places. The ex-

ternal layer is adherent to the bones of the skull, and forms their internal periosteum. The internal layer covers the brain and sends numerous prolongations inward for the support and protection of the different lobes of the brain.[12] These projections also form sinuses that return the blood from the brain, and sheaths for the nerves that pass out of the skull. The spinal dura mater forms a loose sheath around the spinal cord, and consists of only the inner layer of the spinal dura mater; the outer layer ceases at the foramen magnum, and its place is taken by the periosteum lining the vertebral column.

The **arachnoid** is a delicate serous membrane placed between the dura mater and the pia mater, the cranial portion invests the brain loosely and with the exception of the longitudinal fissure it passes over the various convolutions and sulci and does not dip down into them. The spinal portion is tubular and surrounds the cord loosely. Between the arachnoid and the pia mater is a space called the subarachnoid space in which is a certain amount of cerebrospinal fluid.

The **pia mater** is a delicate membrane of areolar tissue containing a network of blood and lymph-vessels. The cranial portion invests the surface of the brain, and dips down into all the crevices and depressions carrying blood-vessels which go to every part. The spinal portion covers, and is closely adherent to the entire surface of the spinal cord, and sends a process into the ventral fissure.

Meningeal spaces and cerebrospinal fluid.—The meningeal membranes and the spaces filled with fluid form a pad enclosing the brain and cord on all sides. Cerebrospinal fluid is formed in the ventricles of the brain from tufts of blood-vessels, and after filling the ventricles and the central canal of the cord escapes, through the thin roof of the fourth ventricle into the subarachnoid space. Consequently the fluid within the ventricles and surrounding the brain is in free communication with that within the central canal of the cord, and the spaces surrounding the cord. The cerebrospinal fluid is a clear limpid fluid, having a specific gravity of only 1.007 to 1.008. It contains traces of proteins and other organic substances. In disease the fluid may be altered in various ways. It varies in quantity and is quickly secreted.

Function.—The cerebrospinal fluid serves as: (1) a nutritive

[12] The falx cerebri and the tentorium cerebelli as well as several sinuses are shown in Fig. 107.

medium for nerve cells just as lymph does for other cells of the body; (2) it acts as a water-bed and thereby lessens chance of injury to the brain and cord.

THE CRANIAL NERVES

The cranial nerves consist of twelve pairs. They each have a superficial and a deep origin. The *superficial or apparent origin* is the point where they emerge from the under surface of the cerebrum and the medulla, but they can be traced back to various centers in the brain, and these centers constitute their *deep origin.*

Classification.—The cranial nerves are of three varieties: (1) afferent or sensory nerves, (2) efferent or motor nerves, and (3) mixed nerves containing both sensory and motor fibers. Many of the cranial nerves arise from several nerve centers, and therefore consist of several bundles of nerve fibers which in some cases are distributed to different parts of the body. After these nerves leave the cranium they split up into branches that are widely distributed.

Numbers and names.—They are named numerically according to the order in which they arise from the brain, and also by names which describe their nature, function, or distribution. The following doggerel may assist the beginner in learning the order of the cranial nerves. Each capital letter denotes a cranial nerve. "On Old Olympic's Terraced Tops, A Finn and German Vaulted A Hedge."

(1) The *olfactory* nerve is the special nerve of the sense of smell. It arises from the central or deep processes of the olfactory cells of the nasal mucous membrane, where its fibers form a network, and are then collected into about twenty branches which pierce the cribriform plate of the ethmoid bone in two groups, and end in the olfactory bulb. Its peripheral fibers are distributed to the upper third of the nasal cavity, and the turbinated bones.

(2) The *optic* nerve is the special nerve of the sense of sight. Its cell bodies are situated in the retinal coat of the eye.

(3) The *oculomotor* (*motor oculi*) nerve supplies, (1) the sphincter muscle of the iris,[13] (2) the ciliary muscle of the eye, (3) the inferior oblique, and the superior, inferior and internal recti. It originates in the anterior corpora quadrigemina.

(4) The *trochlear*, or *pathetic* nerve supplies only the superior oblique muscle of the eye. It arises from a nucleus situated in the floor of the cerebral aqueduct.

[13] See page 481.

(5) The *trigeminal* or *trifacial* is the largest cranial nerve, and is the great sensory nerve of the head and face, and the motor nerve of the muscles of mastication. It has two roots, a dorsal or sensory, and a ventral or motor. The fibers of the motor root arise from two nuclei, a superior located in the cerebral aqueduct, and an inferior located in the upper part of the pons. It is uncertain whether the fibers from the superior nucleus are motor or sensory. The fibers of the sensory root arise from the semilunar ganglion (Gasserian) which lies in a cavity of the dura mater near the apex of the petrous portion of the temporal bone. The fibers from the two roots coalesce into one trunk and then subdivide into three large branches: (1) the ophthalmic, (2) the maxillary, and (3) the mandibular. The ophthalmic branch is the smallest, and is a sensory nerve. It divides into three branches, the lacrimal, the frontal, the nasociliary; and communicates with the oculomotor (motor oculi), the trochlear and the abducent. It supplies branches to the cornea,[14] ciliary body,[15] and iris; to the lacrimal gland and conjunctiva; to part of the mucous membrane of the nasal cavity; to the skin of the eyelids, eyebrow, forehead and nose.

The maxillary, the second division of the fifth, is also a sensory nerve. It divides into many branches, which spread out upon the side of the nose, the lower eyelid, and the upper lip, joining with filaments of the facial nerve.

The mandibular is the largest of the three divisions of the fifth; is both a sensory and a motor nerve; divides into many branches and distributes them to the temple, the lower lip and lower part of the face; the teeth and gums; the muscles of mastication; it also supplies the tongue with the special nerve (lingual) of the sense of taste.

(6) The *abducent* nerve arises from the floor of the fourth ventricle and is a motor nerve. From the nucleus of this nerve, fibers pass to the internal rectus muscle of one eye, and the external rectus of the other.

(7) The *facial* nerve arises from the floor of the fourth ventricle and consists of a motor and sensory part. It supplies motor fibers to most of the muscles of the face and scalp; sensory fibers (taste) to the tongue; secretory fibers[16] to the submaxillary and sublingual glands; and vasodilator fibers to the blood-vessels of these glands.

[14] See page 480. [15] See page 481.

[16] From the standpoint of function, secretory and vasodilator fibers belong to the autonomic system.

(8) The *acoustic* (auditory) nerve[17] is a sensory nerve and contains two distinct sets of fibers, which differ in their origin, destination and function. One set of fibers is known as the cochlear nerve, or nerve of hearing, and the other as the vestibular nerve, or nerve for maintenance of equilibrium.

(9) The *glossopharyngeal* nerve arises from the fourth ventricle, contains both motor and sensory fibers, and is distributed, as its name indicates, to the tongue and pharynx. It supplies motor nerves to the muscles of the pharynx; sensory to the tongue, mucous membrane of the pharynx, tonsils, Eustachian tube, and tympanic cavity of the ear. It also supplies secretory fibers to the parotid gland.

(10) The *vagus* or *pneumogastric* nerve arises from the fourth ventricle and has a more extensive distribution than any of the other cranial nerves, since it passes through the neck and thorax to the abdomen. It contains sensory and motor fibers, the latter are both secretory and inhibitory. It is concerned with respiration, the action of the heart, and the digestive organs. It supplies afferent or sensory fibers to the mucous membrane of the larynx, trachea, and lungs; and to the mucous membrane of the esophagus, stomach, small intestine, and part of the large intestine; secretory fibers to the gastric and pancreatic glands; and inhibitory fibers to the heart.

(11) The *accessory* nerve consists of two parts, a cranial and a spinal. The *cranial* part arises in the floor of the fourth ventricle and its fibers are distributed principally to the pharyngeal and superior laryngeal branches of the vagus. The *spinal* part arises from the spinal cord, joins the cranial part, then separates from it and sends branches to the sternocleidomastoid and trapezius muscles.

(12) The *hypoglossal* nerve is the motor nerve of the tongue. It arises from the hypoglossal nucleus in the fourth ventricle.

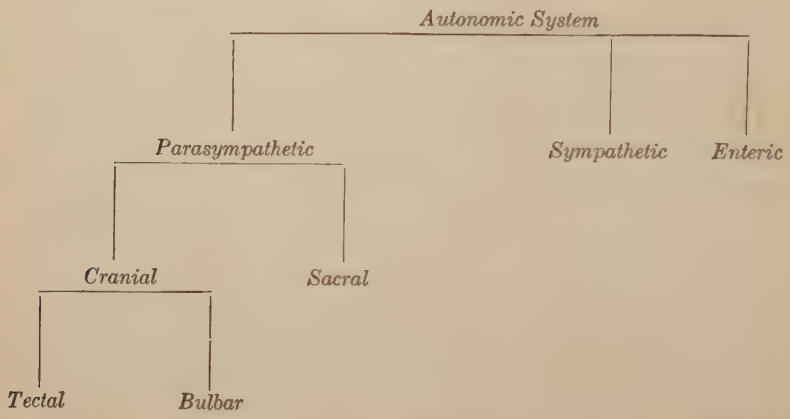
THE AUTONOMIC NERVOUS SYSTEM

This system is called autonomic[18] because it is comparatively independent in its activities. Most of the involuntary activities are mediated through this system which has only indirect connection with the central nervous system. It includes the sympathetic and parasympathetic systems. Much confusion has

[17] See page 473.

[18] Autonomic is more inclusive than sympathetic. There are autonomic pathways beginning in the brain, and others at the lower end of the spinal cord which are not included in the sympathetic system.

arisen due to the various classifications adopted by different physiologists. A classification based on that adopted by Langley, who has contributed much to our knowledge of this subject, is as follows:—



In the autonomic system, two neurones are interposed between the central nervous system, and the organ to be stimulated. The fiber of one neuron located within the brain or spinal cord extends to a sympathetic ganglion, hence is *preganglionic*. From the nerve cells located in the ganglion *postganglionic* fibers are distributed to the organs to be innervated. The autonomic system contains both afferent and efferent neurons, but sensibility in the organs innervated by the afferent neurons is low, or subconscious, hence little is known of their function. The efferent neurons play an important part in the functions of the body.

The preganglionic fibers arise from neurons in the (1) mid-brain, (2) medulla oblongata, (3) the lateral horns of the gray matter of the spinal cord between the second thoracic and second or third lumbar segments, and (4) between the second and fourth sacral segments.

Parasympathetic system.—The portions of the autonomic system that arise in the mid-brain, the medulla, and the sacral segments of the spinal cord are the parasympathetic system. The portions of the parasympathetic that arise in the mid-brain and medulla are called *cranial autonomics*, and are further subdivided into tectal and bulbar autonomics. The portions that arise from the sacral segments of the spine are called *sacral autonomics*.

Cranial autonomics.—The cranial autonomics include: (1) neurons that arise from roots in the mid-brain and become part

of the oculomotor nerve (tectal autonomics); (2) neurons arising from roots in the medulla which emerge in the seventh, ninth, tenth and eleventh cranial nerves, *i.e.*, the facial, glossopharyngeal, vagus and spinal accessory (bulbar autonomics).

Tectal autonomics.—The neurons that arise from roots in the

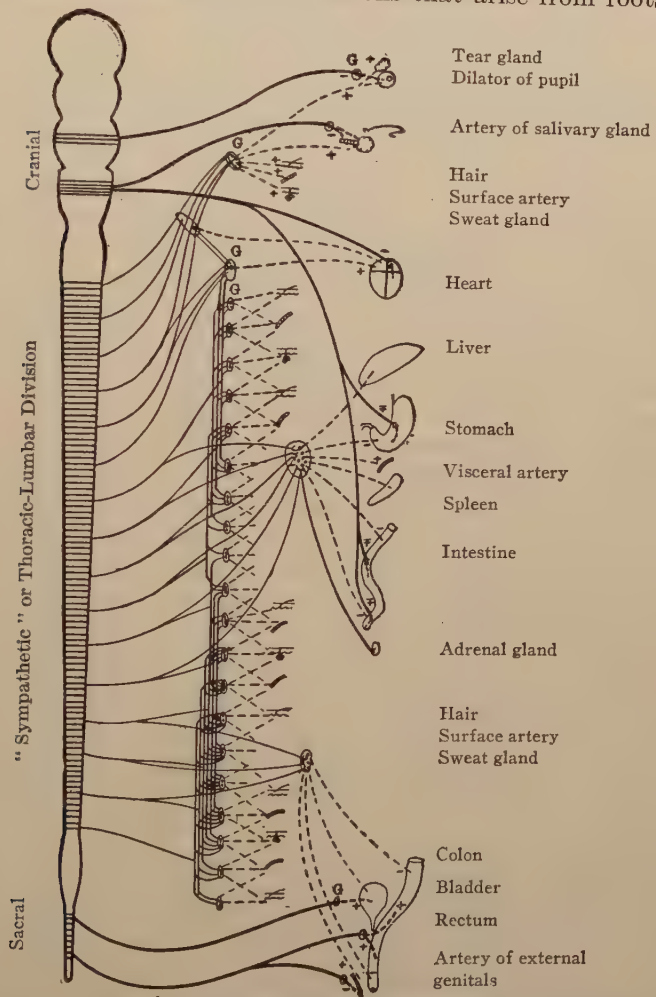


FIG. 111.—DIAGRAM OF THE MORE IMPORTANT DISTRIBUTIONS OF THE AUTONOMIC SYSTEM. The brain and spinal cord are represented at the left. The nerves to skeletal muscles are not represented. The preganglionic fibres of the autonomic system are in solid lines, the postganglionic in dash-lines. The nerves of the cranial and sacral divisions are distinguished from those of the sympathetic or thoracico-lumbar divisions by broader lines. A + mark indicates an augmenting effect on the activity of the organ; a — mark, a depressive or inhibitory effect. From Cannon's Bodily Changes in Pain, Hunger, Fear and Rage, published by D. Appleton & Company.

mid-brain send preganglionic fibers with the oculomotor nerve into the orbit and pass to the ciliary ganglion where they terminate by forming synapses with motor neurons whose axons (postganglionic fibers) proceed as the short ciliary nerves to the eyeballs. These fibers convey motor impulses to the circular muscle of the iris and the ciliary muscle of the eye.

Bulbar autonomics.—Neurons arising from roots in the medulla which emerge in the seventh, ninth, tenth, and eleventh cranial nerves. Fibers of the facial and glossopharyngeal nerves supply vasodilator fibers to the glands and blood-vessels of the nose and mouth. Preganglionic fibers of these nerves terminate in some of the ganglia which are formed in this region, namely, the spheno-palatine, otic,[19] submaxillary and sublingual. The automatic fibers that arise with the vagus (and the accessory) convey motor impulses to the plain muscular tissue of the larynx, esophagus, stomach, small intestine and part of the large intestine; secretory impulses to the stomach, and pancreas; and inhibitory impulses to the heart. Preganglionic fibers of these nerves probably terminate in the local ganglia in or near the organs which they innervate.

Sacral autonomics.—Neurons of the second, third and fourth sacral spinal nerves send fibers to the pelvis where they are collected together to form the pelvic nerve, or nervus erigens, which proceeds to the pelvic plexus[20] from which postganglionic fibers are distributed to the pelvic viscera. Motor fibers pass to the smooth muscle of the descending colon, rectum, anus and bladder. Vasodilator fibers are distributed to these organs, and to the external genitals (penis, scrotum, clitoris, vulva) while inhibitory fibers pass to the smooth muscles of the external genitals. The parts supplied by these nerves are indicated in Fig. 111.

Sympathetic system.—This system correlates activities in widely separated parts of the body and includes: (1) centers in the cervical, thoracic and lumbar regions of the cord; and preganglionic fibers arising in these centers; (2) the sympathetic ganglia and their fibers; (3) the great plexuses that are stimulated by impulses from the sympathetic ganglia.

1. **The sympathetic centers in the spinal cord** are composed of groups of cells lying in the lateral horns of the gray matter of the cord. They give rise to preganglionic fibers.

2. **The sympathetic ganglia** also known as the vertebral and

[19] Otic, of or pertaining to the ear. [20] See page 164.

thoracic-lumbar consist of a chain of ganglia situated on each side of the spinal column, extending from the base of the skull to the coccyx. They are grouped as cervical, thoracic, lumbar, and sacral, and except in the neck they correspond in number to the vertebræ against which they lie:—

Cervical	3 pairs	Lumbar	4 pairs
Thoracic	10-12 pairs	Sacral	4-5 pairs

They are connected with each other by nerve fibers called ganglia cords, and with the spinal nerves by branches which are

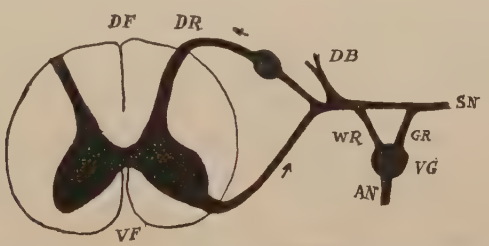


FIG. 112.—DIAGRAM OF SPINAL CORD AND SPINAL NERVE SHOWING SOME OF ITS MAIN BRANCHES. *A.N.*, autonomic or sympathetic nerve; *D.B.* dorsal branch of spinal nerve; *D.F.*, dorsal fissure; *D.R.*, dorsal root; *G.R.*, gray ramus communicans; *S.N.*, spinal nerve; *W.R.*, white ramus communicans; *V.F.*, ventral fissure; *V.G.*, vertebral ganglion.

called *rami communicantes*. Most of the connections consist of two rami, one white and the other gray. See Fig. 112. The white ramus consists of medullated fibers and these pass from the spinal cord to the sympathetic ganglion. They serve for the passage of impulses from the central nervous system to the sympathetic system. The gray ramus consists of non-medullated fibers that pass from the sympathetic ganglion to join the spinal nerve, and so reach the part of the body they are to supply. They serve to carry impulses from the sympathetic ganglia to the glands and plain muscle tissue of all parts of the body. The gray fibers that pass from the sympathetic system into the thoracic and abdominal cavities converge to form two main nerve trunks, the great splanchnic and the small splanchnic. Branches of these nerves pass either directly to the viscera, or they form synapses in the great plexuses.

3. **The great plexuses** consist of masses of gray matter which are located in the thoracic and abdominal cavities. They are the origin of short afferent and efferent fibers that extend between

the different ganglia and viscera. The most important are (*a*) the cardiac plexus located above the heart and innervating it and neighboring parts; (*b*) the celiac or solar plexus located behind the stomach and supplying most of the abdominal viscera; (*c*) the hypogastric plexus situated in front of the last lumbar vertebra and the promontory of the sacrum. These three plexuses connect with many others that are imbedded in the thoracic, abdominal and pelvic viscera.

The enteric system is usually included in the autonomic system. It includes the plexuses of Auerbach and Meissner.[21] The first consists of nerves and ganglia situated between the circular and longitudinal coats of the small intestine which supply nerves to the muscular coats. The second (Meissner) is derived from Auerbach's plexus and is formed by branches that have perforated the circular muscular fibers. It lies in the submucous coat of the intestine. Little is known of the anatomic connections of these plexuses with the central nervous system or of their functional activity which is thought to be control of the peristaltic action of the intestine.

Functions of the autonomic system.—As previously stated the autonomic system innervates (1) all plain muscular tissue in the body, (2) the heart, (3) the glands. The most important factor in the activity of this system is reflex stimulation. While the will cannot influence its activity, it is under the influence of the emotions (probably cerebral.) The ganglia are small relay stations from which nerve impulses from the central nervous system are diffused to visceral structures.

By comparing the distribution of nerves belonging to the parasympathetic and sympathetic systems, it will be found that many of the viscera are supplied with nerves from both divisions. The functions of these two sets are often antagonistic. With the exception of nicotin[22] which paralyzes all autonomic ganglia, most drugs which act on the autonomic system affect principally either the parasympathetic, *e.g.*, atropin, pilocarpin and physostigmin; or the sympathetic, *e.g.*, epinephrin, ergotoxin and cocain.

A few examples of this antagonistic action are listed so that the results following stimulus of these two systems may be compared.

[21] See page 345.

[22] For discussion of the effect of drugs on the autonomic nerve system consult Essentials of Physiology including Pharmacodynamics. Chapter XIII, Bachmann and Bliss. Blakiston's Son and Co.

Pupil of Eye	Parasympathetic—Contraction of the pupils and of the ciliary muscles of the eyes, so that the latter are accommodated to see objects near at hand. Sympathetic—Dilatation of the pupils and lessened tone of the ciliary muscle so that the eyes are accommodated for seeing objects at a distance.
Bronchial Tubes	Parasympathetic—Contraction of the bronchial tubes. Sympathetic—Dilatation of the bronchial tubes.
Heart	Parasympathetic—Slowing and possibly weakening of the heart's action. Sympathetic—Increase in the rate and strength of the heart's action.
Blood-vessels	Parasympathetic—Dilatation of the blood-vessels in the nose, salivary glands, and pharnyx. Sympathetic—Contraction of the blood-vessels supplied with vasoconstrictor nerves.
Salivary Glands	Parasympathetic—Increased secretion of saliva. Sympathetic—Decreased secretion of saliva.
Gastric and Pancreatic Fluid	Parasympathetic—Increased secretion of gastric fluid. Sympathetic—Inhibition of secretion of gastric fluid.
Stomach Intestines Sphincters	Parasympathetic—Increased peristalsis of stomach and intestines with lessened tone of the sphincter muscles. Sympathetic—Decreased activity of the stomach and intestines, and contraction of the sphincters.
Sexual Organs	Parasympathetic—May stimulate sexual activity. Sympathetic—Inhibits sexual activity.

The sympathetic system is strongly stimulated by pain and unpleasant excitement such as rage and terror. The animal responses to rage and terror are fight and flight, and the conditions brought about by stimulating the sympathetic system are such as to favor these responses, *i.e.*, the bronchial tubes are relaxed, and rapid breathing is rendered easier; the contraction of the blood-vessels in the stomach and intestines, and the increased heart action, forces more blood into the skeletal muscles, and thus provides them with the extra oxygen and fuel needed for increased muscular activity; the supply of glucose from the liver is also increased thus furnishing more fuel; and increased perspiration tends to lessen body heat and prevents a rise in temperature. All of these responses are closely connected with the suprarenal capsules which secrete a substance called epinephrin, which secretion is increased in amount when the sympathetic system is stimulated.

Interdependence of the parasympathetic and sympathetic systems.—Marked stimulation of one system, or even part of one system, is likely to stimulate some part of the other system, thus checking excessive stimulation with the bad results that might follow. For example: stimulation of the part of the vagus that supplies the bronchial tubes may cause such marked contraction of the tubes that interference with breathing, pain and distress may result, this in turn stimulates the sympathetic system to lessen the contraction of the tubes. Or another example: the afferent branch of the vagus that is connected with the heart is stimulated by marked contraction of the blood-vessels, and this transmits: (1) inhibitory impulses to the heart, thus slowing its action, (2) inhibitory impulses to the vasoconstrictor center, thus lessening the contraction of the vessels.

All parts of the sympathetic system are stimulated by intense excitement, but the parasympathetic system does not respond to general stimulation because the centers to which the receptors carry stimuli are farther apart, and because its receptors are of various types and therefore respond to different kinds of stimuli.

SUMMARY

Spinal Cord
- Located in spinal canal.
- Extends from foramen magnum to second lumbar vertebra.
- Consists of
  - Gray matter in form of H.
  - On each side white matter is in funiculi
    - Ventral.
    - Lateral.
    - Dorsal.
- **Fissures**
  - Ventral divides front portion in lateral halves.
  - Dorsal divides back portion in lateral halves.
- **Transverse commissure**—connects lateral halves.
- **Canal**—center of isthmus.
- **Membranes**
  - **Pia mater**—inner membrane, closely invests spinal cord.
  - **Arachnoid**—middle membrane.
  - **Dura mater**—outer membrane.
- **Functions**
  - Important center of reflex action.
  - Consists of the principal conducting paths to and from the higher centers.

Spinal Nerves
- **Number**

Cervical	8 pairs.
Thoracic	12 pairs.
Lumbar	5 pairs.
Sacral	5 pairs.
Coccygeal	1 pair.
	31 pairs.

- **Variety**
  - Medullated.
  - Mixed
    - Sensory.
    - Motor.
- **Origin**—two roots
  - Ventral in gray matter of cord.
  - Dorsal in spinal ganglia.
- **Distribution**—two trunks
  - Ventral, supplies extremities, and parts of body in front of spine.
  - Dorsal, supplies muscles and skin of back of head, neck, and trunk.

Embryonic Life Brain Consists of 3 Hollow Vesicles
1. **From the Prosencephalon or Fore-brain**
   - The cerebral hemispheres, their commissures, the first, second and third ventricles are developed.
2. **From the Mesencephalon or Mid-brain**
   - The corpora quadrigemina, the cerebral peduncles, and the cerebral aqueduct are developed.
3. **From the Rhombencephalon or Hind-brain**
   - The medulla oblongata, the pons Varolii and the cerebellum are developed.

Brain
- Located in cranial cavity.
- Covered by meninges—same as spinal cord.
- **Divisions**
  - Cerebrum.
  - Cerebellum.
  - Mid-brain.
  - Medulla Oblongata.
  - Pons Varolii.

Average Weight of Human Brain
- Male—48.6 ounces avoirdupois (about 1380 grams).
- Female—44 ounces avoirdupois (about 1250 grams).

Development of Brain
- Not entirely a matter of growth, but of forming new pathways.
- Nature of brain protoplasm and use to which it is put determine length of time during which development continues.
- Mental exercise tends to keep brain active.

Cerebrum

Description
- Egg-shaped or ovoidal.
- Fills upper portion of skull.
- Gray matter on outside:
  - Fissures.
  - Sulci.
  - Convolutions.
- White matter on inside.
- **Fissures:**
  - Longitudinal cerebral fissure.
  - Transverse fissure.
  - Rolandic or central.
  - Sylvian or lateral cerebral.
  - Parieto-occipital.
- **Lobes:**
  - Frontal.
  - Parietal.
  - Occipital.
  - Temporal.
  - Insula, or Island of Reil.
- **Ventricles:**
  - Lateral ventricles (two).
  - Third ventricle.
  - Fourth ventricle.
  - Fifth ventricle—not a true ventricle.

Function
- Governs all our mental activities:
  - Organ of associative memory.
  - Reason.
  - Intelligence.
  - Will.
  - Higher emotions.
  - Seat of consciousness.
  - Interpreter of sensations.
  - Instigator of voluntary acts.
  - Exerts a controlling force on reflex acts.

Names of Areas
- **Motor area**—in front of Fissure of Rolando.
- **Sense areas:**
  - Visual—occipital lobe.
  - Auditory—superior part of the temporal lobe.
  - Olfactory, Gustatory } anterior part of temporal lobe.
- **Association areas**—cerebral tissue surrounding motor and sense areas, in which as yet no definite functions have been localized.

Cerebellum

Description
- Oval in form, constricted in center.
- Central portion called vermis.
- Lateral portions called hemispheres.
- Gray matter on exterior.
- White matter in interior.
- Connected with cerebrum by superior peduncles.
- Connected with pons by middle peduncles.
- Connected with medulla by superior peduncles.

Function
- Assists in maintaining muscular tone.
- Coördination.
- Maintenance of equilibrium.

Mid-brain

- **Description**
  - Short, constricted portion connects pons and cerebellum with the hemispheres of the cerebrum.
  - Consists of
    - Pair of cylindrical bodies called cerebral peduncles.
    - Four rounded eminences called the corpora quadrigemina.
    - The cerebral aqueduct.

Medulla Oblongata

- **Description**
  - Pyramidal-shaped mass, upward continuation of cord.
  - Gray matter under floor of fourth ventricle
    - Nuclei of fibers that pass to cerebellum and other parts of brain.
    - Nuclei of cranial nerves from the seventh to the twelfth.
    - Nuclei of fibers that transmit impulses to autonomic system.
    - Nuclei of fibers that pass down the cord.
  - Connecting bridge and general crossing place of all conducting paths.
- **Function**
  - Vital centers
    1. Respiratory center.
    2. Vasomotor center.
    3. Cardiac inhibitory center.
  - Reflex centers
    1. For sneezing.
    2. For mastication.
    3. For deglutition.
    4. For sucking.
    5. For coughing.
    6. For vomiting.
    7. For winking.
    8. For secretion of saliva.
    9. For secretion of gastric fluid.

Pons Varolii

- **Description**
  - Situated between the mid-brain and the medulla oblongata. Consists of interlaced transverse and longitudinal white fibers mixed with gray matter.
- **Function**
  - Connects two halves of cerebellum and also medulla with cerebellum.
  - Place of exit for trigeminal, abducent, facial and acoustic nerves.

Meninges or Membranes of Brain and Cord

- **Cranial dura mater**—arranged in two layers. Outer layer adherent to bones of skull; inner layer covers the brain.
- **Spinal dura mater**—consists of only the inner layer, forms a loose sheath around the cord.
- **Arachnoid**—serous membrane placed between the dura mater and pia mater of both brain and cord.
- **Cranial pia mater**—vascular membrane, invests brain, and dips down into crevices and depressions.
- **Spinal pia mater**—is closely adherent to cord and sends a process into the anterior fissure.

Cerebro-spinal Fluid

- Found in meningeal spaces of brain and cord, central canal of cord, and ventricles of the brain.
- Formed in brain ventricles from blood.
- Clear, limpid fluid, specific gravity 1.007 to 1.008.
- Contains traces of protein and other organic substances.
- **Function**
  - Nutritive medium for nerve cells.
  - Acts as a water-bed.

Cranial Nerves

I. Olfactory.
II. Optic.
III. Oculomotor (motor oculi).
IV. Trochlear, or pathetic.
V. Trigeminal, or trifacial.
VI. Abducent.
VII. Facial.
VIII. Acoustic, or auditory.
IX. Glossopharyngeal.
X. Vagus or pneumogastric.
XI. Accessory.
XII. Hypoglossal.

Autonomic System

Parasympathetic

- **Cranial Autonomics**
  - Tectal autonomics—Neurons that arise from roots in mid-brain, pass to ciliary ganglia—terminate by forming synapses with motor neurons, whose axons proceed as ciliary nerves to the eyeballs.
  - Bulbar autonomics—Neurons arising from roots in medulla which emerge in 7th, 9th, 10th and 11th cranial nerves.
- **Sacral Autonomics**
  - Neurons of the 2nd, 3rd, and 4th sacral spinal nerves, send preganglionic fibers to pelvis—form nervus erigens, which proceeds to pelvic plexus.

Sympathetic

1. **Correlates activities in widely separated parts of body and includes centers in the cervical, thoracic and lumbar regions of the cord. They give rise to preganglionic fibers.**
2. **Sympathetic Vertebral or Thoracico-Lumbar**
   - Chain of ganglia situated on either side of spinal column.
   - **Grouped as**

Cervical	3 prs.
Thoracic	10-12 prs.
Lumbar	4 prs.
Sacral	4-5 prs.

   - **Connected**
     1. With each other by ganglia cords.
     2. With spinal nerves by rami communicantes.
     3. With glands and plain muscle tissue. Converge to form—Great splanchnic. Small splanchnic.
3. **Three Great Plexuses**
   - Consists of masses of gray matter in thoracic and abdominal cavities.
   - **Form**
     - Cardiac plexus.
     - Solar plexus.
     - Hypogastric plexus.

     Connects with many others embedded in thoracic and abdominal viscera.

Enteric

- Plexus of Auerbach—consists of nerves and ganglia situated between the circular and longitudinal coats of small intestine.
- Plexus of Meissner—derived from Auerbach's plexus, consists of branches that have perforated the circular fibers.

Function—Innervates (1) all plain muscular tissue, (2) the heart and (3) the glands. Most important factor is reflex stimulation. Not under control of will, influenced by emotions. Ganglia serve as relay stations.

Parasympathetic and Sympathetic Systems

- Many of the viscera are supplied with nerves from both parasympathetic and sympathetic systems—functions of these two sets are often antagonistic.
- These two systems are interdependent, stimulation of one system or part of one system, likely to stimulate some part of the other system.
- Sympathetic system is stimulated by intense excitement.
- Parasympathetic system is not.
- Nicotin paralyzes all autonomic ganglia. Most drugs affect either the parasympathetic or the sympathetic, not both.

CHAPTER IX

EPITHELIAL TISSUE.—SPECIAL MEMBRANES

Epithelial tissue is derived from all three germ layers and is composed entirely of cells united by a minimum amount of cement substance. The cells are generally arranged so as to form a skin, or membrane, covering the external surfaces, and lining the internal parts of the body. It is devoid of blood-vessels, and is nourished by the absorption of lymph which passes to the cells by way of the minute spaces within the intercellular substance.

The varieties of epithelium may be classified in various ways. A very simple classification is as follows:—

- **Epithelial tissue**
  - Squamous
    - Simple
      - Epithelium.
      - Endothelium.
    - Stratified.
  - Columnar
  - Modified
    - Goblet.
    - Ciliated.
    - Neuro-epithelium.

Squamous epithelium.—Where this variety occurs in the form of *one* layer of thin, flat cells, fitted together to form a more or less regular mosaic, it is classed as *simple*.

Fig. 113.—Simple Squamous Epithelium.

Epithelial tissue which lines passages which communicate with the outside is called *epithelium*. It lines the air passages of the lungs.

Epithelial tissue which lines passages which do not communicate with the outside is called *endothelium* (*i.e.*, lying within). It lines the heart and blood-vessels and is derived from the mesoderm.

Squamous epithelium which occurs in the form of several layers of cells is classified as *stratified*. This variety covers the body, and is found wherever the ectoderm folds in from the outside, *i.e.*, mouth, nose, anus.

The cells composing the different layers differ in shape. As a rule, the cells of the deepest layer are columnar in shape; the

next, rounded or many-sided, while those nearest the surface are always flattened and scale-like. The deeper soft cells of a stratified epithelium are separated from one another by a system of channels, which are bridged across by numerous fibers. They

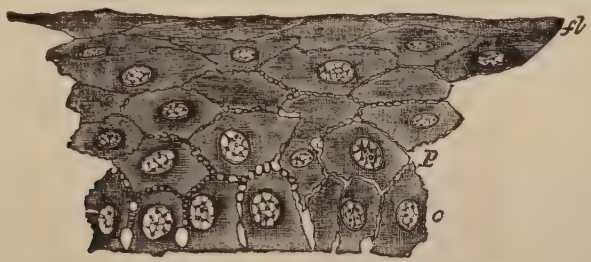


FIG. 114.—SECTION OF STRATIFIED SQUAMOUS EPITHELIUM. *c*, lowermost columnar cells; *P*, polygonal cells above these; *fl*, flattened cells near the surface. Between the cells are seen intercellular channels, bridged over by processes which pass from cell to cell. (Schäfer.)

are continually multiplying by cell division, and as the new cells which are thus produced in the deeper parts increase in size, they compress and push outward those previously formed. In this way cells which were at first deeply seated are gradually shifted outward and upward, growing harder as they approach the surface. The older superficial cells are being continually rubbed off as the new ones continually rise up to supply their places.

FIG. 115.—SIMPLE COLUMNAR EPITHELIUM FROM INTESTINAL MUCOSA.

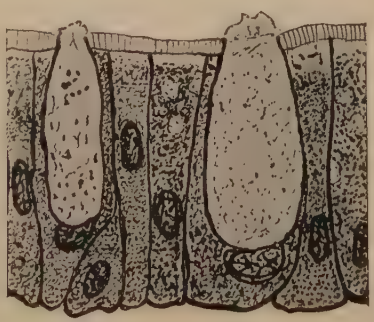


FIG. 116.—GOBLET CELLS FROM EPITHELIUM LINING LARGE INTESTINE.

Columnar epithelium.—In this variety of epithelium the cells have a prismatic shape and are set upright on the surface which they cover. Epithelium consisting of only one layer of prismatic cells constitutes the *simple columnar* variety. It is found lining the stomach and portions of the intestines.

Modified epithelium.—In order to meet particular work epithelial cells may undergo marked *modifications*. When these cells assume a peculiar chalice form resulting from an accumulation of mucoid secretion the cells are called *goblet* or glandular, and may be regarded as the simplest type of glands.[1]

In some localities the free surface of columnar epithelium is provided with minute, hair-like processes, which are agitated incessantly with a lashing or vibrating motion. These minute and delicate processes are named *cilia*, and are active prolongations of the cell protoplasm. The gill of an oyster is extensively provided with ciliated epithelium. A small piece of gill tissue taken from a recently opened oyster and placed under a microscope shows many ciliated surfaces. The manner in which the cilia move is best seen when the tissue is dying or when it is cooled. The motion of an individual cilium may be compared to the lashlike motion of a short-handled whip, the cilium being rapidly bent in one direction. The motion does not involve the whole of the ciliated surface at the same moment, but is performed by the cilia in regular succession, giving rise to the appearance of a series of waves travelling along the surface like the waves tossed by the wind in a field of wheat. When they are in very rapid action, their motion conveys the idea of swiftly running water. As they all move in one direction, a current of much power is produced.

Fig. 117.—Ciliated Epithelium from the Human Trachea. (Highly magnified.) *a*, large ciliated cell; *d*, cell with two nuclei.

Ciliated epithelium is found (1) in the respiratory tract from the nose to the end of the bronchial tubes (with the exception of the pharynx and vocal cords); (2) in the ventricles of the brain and the central canal of the spinal cord; (3) in the uterine tubes and the upper part of the uterus, in the female, and (4) in the efferent ducts of the testes in the male.

Epithelium which contains the end-organs of nerves is described as *neuro-epithelium*, or *sensory*. For example, the epithelium lining the nose contains the end-organs of the olfactory nerve, and the epithelium of the middle ear contains the end-organs of the auditory nerve.

[1] See page 281.

Function.—The most important functions of epithelial tissue are as follows:—

1. *Protection.*—Some varieties are specially modified so as to form protective membranes. Example—skin.

2. *Motion.*—This is seen in the cilia.

In man their use is (*a*) to impel secreted fluids, or other matters, along the surfaces from which they extend, (*b*) to prevent the entrance of foreign matter into the cavities, and (*c*) the cilia of the uterine (Fallopian) tubes[2] help to propel the ova liberated from the ovaries toward the uterus.

3. *Absorption.*—This is particularly well seen in the digestive tract.

4. *Secretion.*—Every secreting organ must contain epithelial cells. Mucous and serous membranes are examples of secreting organs.

5. *Special sensation.*—The organs of the special senses contain epithelial cells. Examples—eye, ear, nose, etc.

MEMBRANE

The word *membrane* in its widest sense is used to designate any thin expansion of tissue. In a restricted, although the commonest sense, the word *membrane* is used to denote an enveloping or a lining tissue of the body.

Classification of membranes.—The chief membranes of the body are classified as (1) serous, (2) synovial, (3) mucous, (4) cutaneous.

SEROUS MEMBRANES

Serous membranes are thin, transparent, tolerably strong, and elastic. The surfaces are moistened by a fluid derived from lymph but called serum, hence the name serous membranes. They are found lining closed cavities and passages that do not communicate with the exterior. They consist of two layers only: (1) endothelium, (2) corium, which consists of a thin layer of fibrous tissue,[3] and contains blood-vessels, lymph-vessels, and lymphoid tissue.

Serous membranes are attached to the underlying parts by areolar tissue,[4] called *subserous* tissue. They may be divided into three classes:—

(1) Serous membranes proper.
(2) The lining membrane of the vascular system.
(3) The lining membrane of certain cavities.

[2] See page 507. [3] See page 25. [4] See page 23.

(1) **Serous membranes proper.**—With one exception, these membranes form closed sacs, one part of which is attached to the walls of the cavity which it lines,—the *parietal* portion,—whilst the other is reflected over the surface of the organ or organs contained in the cavity, and is named the *visceral* portion of the membrane. In this way the viscera are not contained within the sac, but are really placed outside of it, and some of the organs may receive a complete, while others receive only a partial, or scanty, investment.

FIG. 118.—THE ANTERIOR ANNULAR LIGAMENT OF THE ANKLE AND THE SYNOVIAL MEMBRANES OF THE TENDONS BENEATH IT. Artificially distended. (Gerrish.)

This class of serous membranes includes:—

(*a*) *The two pleuræ*, which cover the lungs and line the chest.

(*b*) *The pericardium*, which covers the heart, and lines the outer fibrous pericardium. (See Fig. 128.)

(*c*) *The peritoneum*,[5] which lines the abdominal cavity, clothes its contained viscera, and also the upper surface of some of the pelvic viscera.

(2) **The lining membrane of the vascular system.**—This applies to the internal coat of the heart, blood-vessels, and lymphatics. It bears a close resemblance to the serous membranes in structure and appearance.

(3) **The lining membrane of certain cavities:—**

(*a*) One illustration of this is the fascia bulb or capsule of Tenon. This membrane envelops the bulb of the eye, from the optic nerve to the ciliary region, and separates the eye-ball from the bed of fat on which it rests.

(*b*) The brain and spinal cord enclose cavities which are lined with a delicate serous membrane. One of the membranes that envelop the brain and spinal cord (arachnoid) presents all the elements of a serous membrane.

[5] The peritoneum in the female is the one exception to the rule that serous membranes are perfectly closed sacs, as it has two openings by which the uterine (*Fallopian*) tubes communicate with its cavity.

Function of serous membranes.—The most important function of serous membrane is protection, which is accomplished in two ways: (1) by forming a smooth, slippery lining or covering for the blood-vessels, cavities, and viscera with which it is associated, and (2) by secreting serum which acts as a lubricating fluid and tends to lessen friction.

The inner surface of a serous membrane is free, smooth, and polished; and in the case of serous membranes proper, the inner surface of one part is applied to the corresponding inner surface of some other part, only a very small quantity of fluid being interposed between the surfaces. The organs situated in a cavity lined by a serous membrane, being themselves also covered by it, can thus glide easily against its walls or upon each other, their motions being rendered smoother by the lubricating fluid.

SYNOVIAL MEMBRANES

Synovial membranes are frequently classed as serous membranes, because their function is the same and they have no communication with the surface of the body. They differ, however, (1) in the nature of their secretion, (2) in their structure, and (3) they are associated with the bones and muscles, and not with the viscera. Synovial membrane is composed of thin delicate connective tissue and secretes a viscid glairy fluid that resembles the white of egg, and is named *synovia*.

They are divided into three classes, *viz.* (1) articular, (2) mucous sheaths, and (3) bursæ mucosæ.

1. **Articular synovial** membranes are found surrounding and lubricating the cavities of the movable joints in which the opposed surfaces glide on each other. (See Fig. 63.)

2. **Mucous sheaths** are found forming sheaths for the tendons of some of the muscles, thus facilitating their motion as they glide in fibroösseous canals. They are elongated closed sacs; one layer adheres to the wall of the canal, and the other to the enclosed tendon.

3. **Bursæ mucosæ** or synovial bursæ, are found in the form of simple sacs, interposed, to prevent friction, between two surfaces which move upon each other. They may be subcutaneous, submuscular, subfascial and subtendinous. The large bursa, situated over the patella is an example of a subcutaneous bursa. Similar, though smaller, bursæ are found over the olecranon, the malleoli, the knuckles, and other prominent parts

MUCOUS MEMBRANES

The mucous membranes, unlike the serous membranes, line passages and cavities which communicate with the exterior. Their surfaces are coated over and protected by mucus, from which the membrane derives its name. The mucous membranes of different parts are continuous, and they may nearly all be reduced to two great divisions; namely, (1) gastropulmonary, and (2) the genito-urinary.

(1) **Gastropulmonary.**—The gastropulmonary mucous membrane lines the inside of the alimentary canal, the air passages, and the cavities communicating with them. It commences at the edges of the lips and nostrils, proceeds through mouth and nose to the throat, and thence is continued throughout the entire length of the alimentary canal to the anus. At its origin and termination it is continuous with the external skin. It also extends throughout the trachea, bronchial tubes, and air

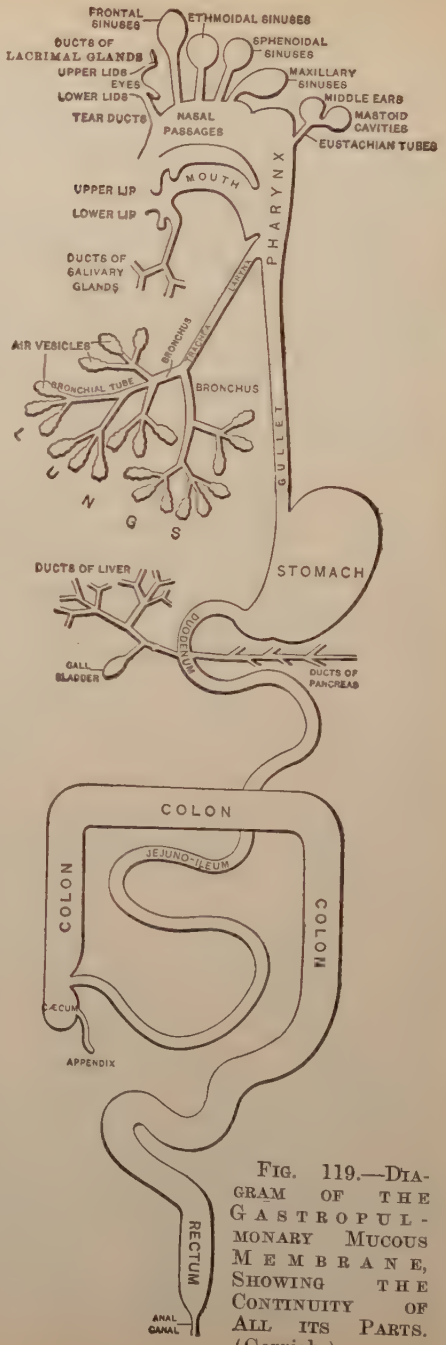


FIG. 119.—DIAGRAM OF THE GASTROPULMONARY MUCOUS MEMBRANE, SHOWING THE CONTINUITY OF ALL ITS PARTS. (Gerrish.)

sacs. From the interior of the nose the membrane is prolonged into the frontal, ethmoidal, sphenoidal, and maxillary sinuses, also into the lacrimal passages, and under the name of conjunctival membrane, over the fore part of the eyeball and inside of the eyelids, on the edges of which it again meets with the skin. From the upper and back part of the pharynx a prolongation extends on each side, along the passage to the ear—Eustachian tube[6]—and offsets in the alimentary canal go to line the salivary, pancreatic, and biliary ducts, and the gall-bladder.

(2) **Genito-urinary.**—The genito-urinary mucous membrane lines the inside of the bladder, and the whole urinary tract from

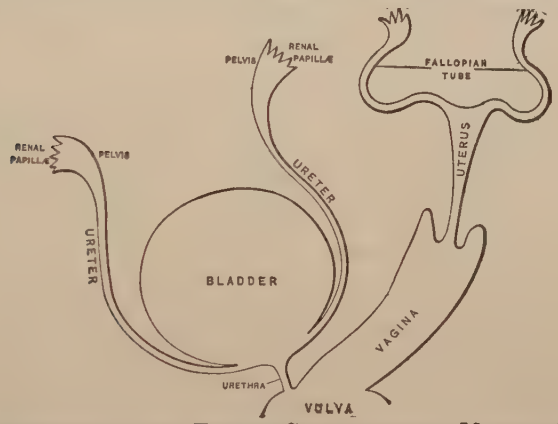


FIG. 120.—DIAGRAM OF THE FEMALE GENITO-URINARY MUCOUS MEMBRANE, SHOWING CONTINUITY OF ALL ITS PARTS. (Gerrish.)

the interior of the kidneys to the meatus urinarius, or orifice of the urethra; in the female it also lines the vagina, uterus, and uterine (Fallopian) tubes. A study of Figs. 120 and 121 will make this plain.

Structure.—A mucous membrane is composed of four layers of tissue (1) epithelium, (2) basement membrane, (3) corium; and (4) muscularis mucosæ.

(1) *Epithelium* is the surface layer. It may be stratified, as in the throat; columnar, as in the intestine; or ciliated, as in the respiratory tract.

(2) The *basement membrane* consists of a layer of flattened cells, and is really part of the corium.

(3) The *corium* is composed of either areolar[7] or lymphoid connective tissue and contains blood vessels.

[6] Named after Eustachio, a famous Italian anatomist, died 1574.

[7] See page 23.

(4) The *muscularis mucosæ* consists of a thin layer of muscular tissue.

The mucous membranes are attached to the parts beneath them by areolar tissue, here named *submucous*. This differs greatly in quantity as well as in consistency in different parts. The connection is in some cases close and firm, as in the cavity of the nose. In other instances, especially in cavities subject to frequent variations in capacity, like the œsophagus and the stomach, it is lax; and when the cavity is narrowed by contraction of its outer coats, the mucous membrane is thrown into folds, or *rugæ*, which disappear again when the cavity is distended. In certain parts the mucous membrane forms permanent folds that cannot be effaced, and these project conspicuously into the cavity which it lines. The best-marked example of these folds is seen in the small intestine, where they are called *circular folds* (valvulæ conniventes[8]) which are doubtless provided for increasing the amount of absorbing surface for the products of digestion. In some locations the free surface of mucous membrane contains minute glands, or is covered with papillæ,[9] villi,[10] or cilia.[11]

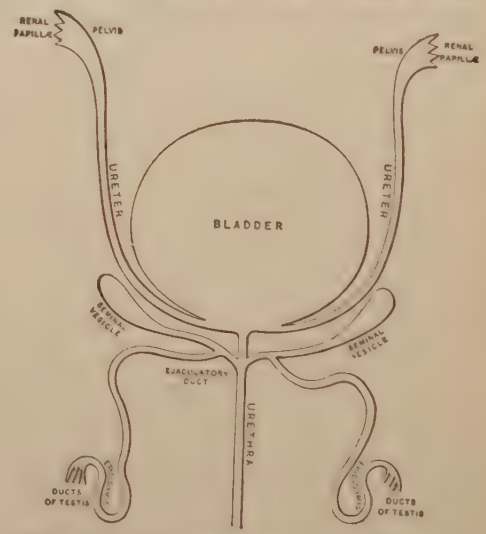


FIG. 121.—DIAGRAM OF THE MALE GENITO-URINARY MUCOUS MEMBRANE SHOWING CONTINUITY OF ALL ITS PARTS. (Gerrish.)

Function of mucous membranes.—The function of mucous membranes is (1) protection, (2) support of blood-vessels and lymphatics, (3) to furnish a large amount of surface for absorption.

(1) It protects by forming a lining or inside skin for all the passages that communicate with the exterior. These passages are subject to the contact of foreign substances, which are introduced into the body; and waste materials, which are expelled from

[8] See page 343. [9] See page 464.
[10] See page 343. [11] See page 174.

the body. The mucus which it secretes is a thicker and more sticky fluid than either serum or synovia, and by coating the surface lessens the possibility of irritation from food, waste materials, or secreted substances. The cilia of the respiratory tract also assist in the function of protection. They keep up an incessant motion, and thus carry mucus toward the outlet of these passages. Dust and foreign materials usually become entangled in the mucus and are forced out with it.

(2) The redness of mucous membranes is due to their abundant supply of blood. The small blood-vessels which convey blood to the mucous membranes divide in the submucous tissue, and send smaller branches into the corium, where they form a network of capillaries just under the basement membrane. The lymphatics also form networks in the corium, and communicate with larger vessels in the submucous tissue below.

(3) The modifications of mucous membrane, such as the circular folds (See Figs. 194 and 195) and villi, are largely for the purpose of increasing the surface for absorption, and also to enable it to carry more blood-vessels and lymphatics.

CUTANEOUS MEMBRANE

By this term is indicated the membrane which covers the body and is commonly spoken of as skin. It is a complex structure, and has several functions in addition to serving as a protective covering for the deeper tissues lying beneath it. It will be more fully considered in Chapter XXI.

SUMMARY

Epithelial—tissues of cells and little intercellular substance.

Classification of Epithelial Tissues
- Squamous
  - Simple—one layer of flat cells
    - Endothelium.
    - Epithelium.
  - Stratified—several layers of cells.
- Columnar—cells set upright on surface.
- Modified
  - Goblet—chalice shape.
  - Ciliated—microscopic, hair-like processes at free surface.
  - Neuro-epithelium contains end-organs of nerves.

Function
- Protection.
- Motion.
- Absorption.
- Secretion.
- Special sensation.

Membranes

- **Definition**
  - Any thin expansion of tissue.
  - An enveloping or lining tissue.
- **Varieties**
  1. Serous membranes.
  2. Synovial membranes.
  3. Mucous membranes.
  4. Cutaneous membranes.

SEROUS MEMBRANES

- **Consist of**
  1. Endothelium—a single layer of flat cells.
  2. Corium—a thin layer of fibrous tissue.
- **Found**—lining closed cavities or passages that do *not* communicate with the exterior. They are moistened by *serum*, derived from lymph.
- **Three Classes**
  - Serous membranes proper
    - Pleuræ—cover the lungs and line the chest.
    - Pericardium—covers the heart and lines the outer fibrous pericardium.
    - Peritoneum—covers the abdominal and the top of some of the pelvic organs, lines the abdominal cavity.
  - Lining membrane of vascular system
    - Heart.
    - Blood-vessels.
    - Lymphatics.
  - Lining membrane of certain cavities
    - Back of eye—fascia bulb.
    - Lining membrane of the cavity of the central nervous system.
- **Function—Protection**
  1. Furnishes a cover or lining
     - Viscera.
     - Vascular system.
     - Certain cavities.
  2. Furnishes a secretion—serum—which acts as a lubricant.

SYNOVIAL MEMBRANES

- **Consist of** thin delicate connective tissue.
- **Three Classes**
  - Articular synovial membranes—Surround cavities of movable joints.
  - Mucous sheaths—Form sheaths for tendons.
  - Bursæ mucosæ—Sacs interposed between two surfaces which move upon each other.
- **Function**
  - Furnishes a cover or lining
    - Joints.
    - Tendons.
    - Sacs under skin, muscles and tendons.
  - Furnishes a secretion—synovia—which acts as a lubricant.

MUCOUS MEMBRANES

- **Found**—Lining passages that communicate with the exterior and are protected by *mucus*.
- **Two Divisions**
  - Gastropulmonary
    - Alimentary canal.
    - Air-passages.
    - Cavities communicating with both alimentary canal and air-passages.
  - Genito-urinary
    - Urinary tract.
    - Generative organs.
- **Consist of**
  1. Epithelium
     - Stratified.
     - Columnar.
     - Ciliated.
  2. Basement membrane, a layer of flat cells.
  3. Corium
     - Areolar, or
     - Lymphoid tissue, and contains blood vessels
  4. Muscularis mucosæ—thin layer of muscular tissue.

MUCOUS MEMBRANES

- **Modifications**
  - Rugæ—temporary folds
    - Esophagus.
    - Stomach.
  - Circular folds—permanent folds of mucous membrane found in small intestine.
  - Papillæ—conical processes of mucous membrane best seen on tongue. Contain blood-vessels and nerves.
  - Villi—tiny thread-like projections of the mucous membrane of small intestine.
  - Cilia—hair-like processes.
- **Function**
  - Protection
    - Inside skin.
    - Secretion of mucus.
    - Action of cilia.
  - Support—for network of blood-vessels.
  - Absorption—Various modifications increase the surface.

CHAPTER X

THE BLOOD; THE CLOTTING OF THE BLOOD

It is helpful to recall that the body consists of an enormous number of individual cells, and that each cell must be supplied with materials to enable it to carry on its activities, and at the same time it must have the waste materials that are the result of its activities removed. Many cells are far from the source of supplies and the organs of elimination; hence the need of a medium to distribute supplies and collect waste, and the need of a system so that the distribution will be orderly and systematic. These two needs are met by the *vascular system*, the divisions of which may be outlined as follows:—

- **Vascular System**
  - Circulating fluids
    - Blood.
    - Lymph.
  - Systems
    - Blood vascular.
    - Lymph vascular.

THE BLOOD

Characteristics.—The most striking external feature of the blood is its well-known color, which is blood red, approaching to scarlet in the arteries, but of a dark red or crimson tint in the veins.

It is a somewhat sticky liquid, a little heavier than water; its specific gravity averages about 1.055. It has a peculiar odor, a saltish taste, a temperature of about 100° F. (37.8° C.), and a reaction that is slightly alkaline (average 7.35 pH).[1]

Quantity of blood.—The quantity of blood contained in the body of an adult is estimated to be about $\frac{1}{20}$ of the body weight. This, in an individual weghing 160 pounds (80 kilos), would weigh about 8 pounds (4 kilos), or measure 4 quarts (4 liters).

Functions of the blood.—Blood is commonly spoken of as the nutritive fluid of the body. This is correct, but it is more than a nutritive fluid, as will be seen from the following list of its functions:—

(1) It serves as a medium for the interchange of gases, *e.g.*, carries oxygen to the cells and carbon dioxide from the cells.

[1] An alkaline solution is one in which the hydroxyl ions (OH) are in excess. An acid solution is one in which the hydrogen ions (H) are in excess. A neutral solution is one in which the hydroxyl and hydrogen ions are in equal concentration. In physiology the concentration of hydrogen ions is expressed for convenience sake as the hydrogen exponent (symbol pH). The potentiometer is an instrument for measuring the relative concentration of hydrogen and hydroxyl ions, and on it substances having a pH of 7 are neutral, from 7 to 14 are alkaline, and from 7 to 1 are acid.

(2) It serves as a medium for the interchange of nutritive and waste materials, *e.g.*, carries food that has been prepared by the digestive organs to the cells and waste materials from the cells.

(3) It serves as a medium for the transmission of internal secretions. The presence of these secretions controls the chemical activities of cells.

(4) It aids in equalizing the temperature of the body. Blood passing through a tissue which is undergoing lively metabolism will have a higher temperature when it leaves than it had when it entered. This extra temperature will be lost in passing through a tissue that is not so active. In this way an average temperature is maintained.

(5) It aids in equalizing the water content of the body.

(6) It aids in protecting the body from toxic substances.

Composition of the blood.—Seen with the naked eye, the blood appears opaque and homogeneous; but when examined with a microscope it is seen to consist of minute particles called *cells* or corpuscles floating in a transparent, slightly yellowish fluid called *plasma*.

- **Blood**
  - **Cells or Corpuscles**
    - Red or erythrocytes.
    - White or leucocytes.
    - Blood-platelets or thrombocytes.
  - **Plasma**

Red cells.—The red cells appear as circular biconcave discs, with rounded edges. The average size is about 7.7 μ[2] (0.0077 mm.) in diameter. Because of their extremely small size, the red cells do not appear red when viewed singly with a microscope, but merely of a yellowish red tinge, or yellowish green in venous blood. It is only when great numbers of them are gathered together that a distinctly red color is produced.

Red cells consist of a colorless, filmy, elastic framework or stroma, in which hemoglobin is deposited. They have no nuclei, are soft, flexible, and elastic, so that they readily squeeze through apertures and passages narrower than their own diameters, and immediately resume their proper shape.

Hemoglobin.—Hemoglobin is a substance which is formed of hematin, an iron containing compound and a protein named globin. The proportion of iron in hemoglobin is about .33 per cent. In the presence of oxygen hemoglobin has the power to combine with it to form an unstable compound called oxyhemoglobin, and in an environment where oxygen is scarce, it gives up this oxygen, and is then known as reduced hemoglobin.

[2] The micron (symbol μ) equals one thousandth of a millimeter (0.001 mm.)

For various units of measurement in micrometry see The Microscope by Gage, page 150., 1925 edition.

Function of the red cells.—The red cells, or erythrocytes are *oxygen carriers.* This function is entirely dependent upon the presence of hemoglobin. Exposed to the air in the lungs the hemoglobin becomes fully charged with oxygen and is known as oxyhemoglobin. The red cells carry this oxyhemoglobin to the cells of the tissues, where it gives up the loosely engaged oxygen. It is then known as reduced hemoglobin and is ready to be carried to the lungs for a fresh supply. The color of the blood is dependent upon the combination of the hemoglobin with oxygen; when the hemoglobin has its full complement of oxygen, the blood has a bright red hue; when the amount is decreased, it changes to a dark crimson hue. The scarlet blood is usually found in the arteries, and is called arterial; the dark crimson in the veins, and is called venous blood.

Hemolysis or laking.[3]—Any destruction of the form of red cells is called hemolysis or laking. It may be brought about by (1) the addition of a small amount of ether or chloroform, (2) free dilution with water, (3) alternate freezing and thawing, (4) addition of bile salts, (5) action of foreign blood serums, (6) various hemolysins, such as snake venom, the products of defective metabolism and bacterial invasion. Red cells which have lost their hemoglobin are colorless and incapable of serving as oxygen carriers.

Number of red cells.—The average number of red cells in a cubic millimeter of healthy blood is given as 5,000,000 for men, and 4,500,000 for women. Pathological conditions may cause a marked diminution in number, and differences have been observed even in health. The number varies with altitude; temperature; the constitution, nutrition and manner of life; with age, being greatest in the fetus and new-born child; with the time of day, showing a diminution after meals; in the female menstruation is accompanied by an increase and pregnancy by a decrease.

Polycythemia.—An increase of red cells above the normal number is termed polycythemia. This condition is not common but when there has been a marked loss of water from the blood, the number per cubic millimeter is increased, though the total number in the body is not. Conditions associated with cyanosis and residence in high altitudes are usually followed by polycythemia. Due to the low atmospheric pressure existing in high altitudes it is thought that the ability of the hemoglobin to

[3] Before transfusing blood from one human being to another, the blood of the donor is always tested in several ways. The purpose of one test is to make sure that it will not hemolyze the red cells of the recipient, and thus cause death.

combine with oxygen is lessened, and this reduction of oxygen tends to stimulate the formation of new cells. This result represents the chief benefit anemic people derive from residence in high altitudes.

Anemia.—This term is applied to conditions associated with a deficiency of red cells, or a deficiency of hemoglobin in the cells. A deficiency of red cells results from: (1) hemorrhage, (2) hemolysis, (3) inability to produce new red cells due to lack of nutritious food, diseases of the bone-marrow, and various infections. A deficiency of hemoglobin is associated with many pathological conditions. The percentage of hemoglobin can be obtained by comparing the color of blood with standard color comparators. Normal blood is considered 100 per cent. The number of erythrocytes is obtained by microscopic examination, and the normal number is considered 100 per cent. From these the color index can be derived as follows: use the percentage of hemoglobin as the numerator and the percentage of red cells as the denominator of a fraction, *e.g.*, $\frac{100}{100}$. If the number of cells is normal it is reckoned as 100 per cent and if the hemoglobin is reduced to 70 per cent this gives us $\frac{70}{100}$ or $\frac{7}{10}$ and shows that the cells contain only $\frac{7}{10}$ of their normal amount of hemoglobin.

Life cycle of the red cells.—During the early stages of fetal development all the red cells are nucleated and are termed erythroblasts. They multiply by the process of simple division or fission and this occurs in the liver, spleen, lymphatic tissues and bone-marrow. As development progresses, the formation of cells in the first three tissues decreases, but increases in the bone-marrow, particularly the red marrow which under normal conditions of health is probably the only location in which red cells are formed after birth. Nucleated red cells are found only where cell divisioning is in progress. Before entering the blood-stream they lose their nuclei and then they are termed erythrocytes. Conditions caused by a decrease in the number of red cells normally act as a stimulus for their formation and hasten their passage into the blood-stream. Following hemorrhage or any condition which causes a marked diminution in the number of red cells, nucleated cells will pass into the blood. Erythrocytes have no nuclei, and are probably incapable of (1) independent motion, (2) repairing their own waste, or (3) reproducing themselves. They are carried along passively in the blood-stream and gradually undergo disintegration. Their final destruction takes place in the liver, lymph-nodes and the spleen. The hematin set free from the destroyed cells is changed to bile-pigment. Some of the iron liberated is excreted but most of it

is retained and utilized for the formation of fresh hemoglobin, needed by the new cells being formed in the bone-marrow.

White cells.—The white cells are typical cells containing a nucleus, sometimes two or three nuclei. They are variable in size, some are much larger and some are much smaller than the red cells. They are grayish (not white) in color, and not surrounded by a clearly recognizable membrane.

Number of white cells.—The number of white cells in a cubic millimeter of healthy blood is from 5000 to 7000, a proportion of about one white to 700 red. An increase in number is designated as *leucocytosis*, a decrease as *leucopenia*. Physiological leucocytosis up to 9000 occurs under normal conditions, such as digestion, exercise, or cold baths. Pathological leucocytosis 10,000 or more is found in practically all infectious processes except typhoid and tuberculosis. A leucocytosis is demonstrated by a "blood count," *i.e.*, counting the white blood cells in a given volume of a known dilution of blood, using special pipettes and ruled slides, under the microscope.

Varieties of white cells.—The white cells are classified according to the shape and size of their cell bodies and nuclei, or according to the way in which they behave toward anilin dyes. They are usually divided into two principal groups, and these again into several others as follows:

1. **Lymphocytes**
   - (*a*) Small.
   - (*b*) Large.
2. **Leucocytes**
   - (*a*) Polymorphonuclear or neutrophils.
   - (*b*) Eosinophils or acidophils.
   - (*c*) Mast-cells or basophils.
   - (*d*) Monocytes.

Lymphocytes are not granular and do not show marked ameboid movement.

(*a*) *Small lymphocytes* possess a small amount of clear cytoplasm, a relatively large nucleus and are about as large as the red cells.

(*b*) *Large lymphocytes* are larger than the first mentioned and have a greater amount of cytoplasm, but are few in number.

Leucocytes are granular and show marked ameboid movement.

(*a*) *Polymorphonuclear leucocytes or neutrophils* have a nucleus that is lobulated, and the granules of the cytoplasm stain with neutral dyes. They form about 70% of the total number of leucocytes.

(*b*) *Eosinophilic leucocytes or acidophils* are similar in size and structure to the polymorphonuclear forms, but the granules of the cytoplasm stain with acid dyes such as eosin.

(*c*) *Mast-cells or basilophilic leucocytes,* have a polymorphic nucleus, and the granules of the cytoplasm stain with basic dyes. They are found in small numbers.

(*d*) *Monocytes* are large leucocytes with a single nucleus.

The proportion of the different classes present in the blood, has been found to vary during diseased conditions, especially during infections, and has come to have a practical value in diagnosis of disease by blood examination.

Ameboid movement.—Under favorable circumstances the leucocytes exhibit a movement of their protoplasm which is similar to that of the ameba, hence they are called *wandering cells* and the process is spoken of as migration. It occurs under normal conditions, but is vastly accelerated under pathological conditions.

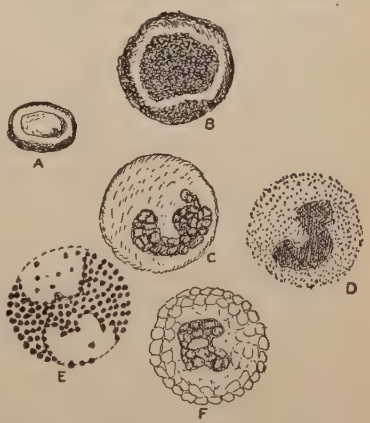


FIG. 122.—VARIETIES OF WHITE CELLS FOUND IN HUMAN BLOOD. When stained with blood-stains various kinds of white cells can be distinguished. Five varieties are shown above. *A*, lymphocyte; *B*, monocyte; *C*, *D*, polymorphonuclear leucocyte; *E*, eosinophilic leucocyte; *F*, mast cell.

Functions of the white cells.—The functions of the white blood cells are supposed to be different for different forms. The most important functions are: (1) they help to protect the body from pathogenic bacteria, and other foreign organisms. It is assumed that they either ingest bacteria and thus destroy them directly, or that they form certain substances called *bacteriolysins,*[4] which have the power of destroying them. Leucocytes which ingest bacteria are called phagocytes, and the process is called phagocytosis.[5] According to some authorities this power is dependent upon certain substances called *opsonins*[6] which are found in the blood and which prepare the bacteria for ingestion by the leucocytes. (2) They promote tissue repair by stimulating the processes of absorption and growth. Accumulated evidence indicates that leucocytes can manufacture growth-producing substances out of materials furnished by the blood. It

[4] See page 193.

[5] This theory is known as the "phagocytosis theory of Metchnikoff." The polymorphonuclear leucocytes are thought to be most active in attacking bacteria, and Metchnikoff called them microphages.

[6] From opsono, I prepare food for. The opsonin content of the blood can be determined experimentally and is spoken of as the opsonic index.

is supposed that these substances enable epithelial and connective tissue cells to reproduce. (3) They aid in absorption from the intestines. (4) They contain a substance which when liberated plays an important part in the clotting of the blood. (5) It is thought that they aid in keeping up the normal supply of blood proteins found in the plasma. The blood proteins are not those found in digested food, and it may be that the leucocytes act as unicellular glands forming the typical blood-proteins, and as a result of their metabolism aid in keeping up the normal supply of blood proteins.

Inflammation.—When any of the tissues become inflamed either as the result of injury or infection, the first effect is irritation, followed by an increased supply of blood to the part. If the irritation continues or is severe, the flow of blood begins to slacken, and a condition of stasis or engorgement results. The leucocytes become particularly active and migrate through the walls of the blood-vessels into the infected tissues in large numbers. Some of the blood-plasma exudes, and a small number of red cells are forced through the capillary walls. This general condition is described as inflammation, and the symptoms of pain, heat, redness, swelling and loss of function are due: (1) to irritation caused by the toxins of the bacteria, (2) to the increased supply of blood, (3) to the engorgement of the blood-vessels, and (4) to the collection of fluid in the tissues, which is spoken of as inflammatory exudate. Under these conditions a death struggle between the leucocytes and bacteria takes place. If the leucocytes are victorious, they not only kill the bacteria but remove every vestige of the struggle, and find their way back to the blood. This process of recovery is described as resolution, and is dependent upon the individual's resistance, *i.e.*, the rapid formation of phagocytes and opsonins.

If the bacteria are victorious, large numbers of phagocytes and tissue cells will be destroyed and suppuration, *i.e.*, the formation of pus ensues. Pus consists of dead and living bacteria, phagocytes, disintegrated tissue cells, and material that has exuded from the blood-vessels.

Also, in the case of a wound, the leucocytes, by virtue of their ameboid movements, escape from the blood-vessels, accumulate in the region of the wound, and act as barriers against infection. When inflammation is so deeply seated that the local symptoms cannot be observed, knowledge of the increase of the white cells is of assistance in determining the severity of the infection, and the degree of resistance being offered by the body. This requires

not only an absolute count, *i.e.*, the total number of white cells in a cubic millimeter of blood, but also the differential count, *i.e.*, the relative number of each type of leucocytes, particularly the number of neutrophils. In making a differential count the number of each kind of white cells in a hundred is counted. A high absolute count, with a high neutrophil percentage, indicates severe infection and good body resistance. A high absolute count with a moderate polynuclear percentage indicates a moderate infection and good resistance. A low absolute count with a high polynuclear percentage indicates severe infection and weak resistance.

Life cycle of white cells.—It is thought that lymphocytes arise in the lymphoid tissue of the lymph-nodes, and the lymph-nodules surrounding many of the mucous cavities, and that leucocytes are derived from cells of the bone-marrow called myelocytes. We do not know the term of existence of the white cells, or where they are destroyed, except that large numbers are lost in the battle waged against bacteria, others by hemorrhage, and others may be converted into granulation tissue.

Blood-platelets or thrombocytes.—They are irregularly shaped bodies of protoplasm, which vary in size but are always smaller than the red or white cells. They usually disintegrate and entirely disappear when the blood is removed from the circulatory system, hence they are difficult to observe and study.

Function.—It is thought that the blood-platelets help in the clotting of blood. When exposed to air and rough surfaces, (conditions accompanying a wound and hemorrhage) large numbers of blood-platelets are disintegrated and set free a substance known as tissue extract. They also help to furnish the blood with prothrombin. Both of these substances are essential to clotting.[7]

Plasma.—The plasma of the blood is a complex fluid of a clear amber color containing a great variety of substances as might be inferred from its double relation to the cells, serving as a source of nutrition and as a means of removing the waste products that result from their functional activity. Consult table included in summary page 199.

Water.—More than eight tenths of the plasma is water. This proportion is kept fairly constant by kidney activity coupled with continual exchanges of fluid which take place between the blood, the lymph, and the cells.

Blood-proteins.—Three proteins are usually described as existing in the plasma of circulating blood, *i.e.*, fibrinogen, paraglobulin, and serum-albumin, but there are indications that the actual

[7] See page 193.

number of proteins is much greater. The first two of these proteins belong to the group of globulins and hence have many properties in common. Serum-albumin belongs to the group of albumins[8] of which white of egg constitutes another member. We know little of their mode of origin, place of formation, and the particular value of each in the body, except in the case of fibrinogen, which is probably formed in the liver and aids in clotting of the blood.

Nutrients.—These are the end products resulting from digestion of food; amino-acids derived from proteins; glucose derived from carbohydrates; and fats. Under normal conditions amino-acids are present in a small proportion; glucose and fat are present in about the same proportion, *i.e.*, 0.07 to 0.1 per cent. A temporary increase in the amount may follow the ingestion of a large quantity.

Salts.—The salts found in the blood are derived from the food and from the chemical reactions going on in the body. The most abundant is sodium chlorid.

Waste substances.—Purin bases, urea, uric acid, creatinin and many other waste substances thrown off from the cells, are in the blood on their way to be excreted by the kidneys or other organs of elimination.

Gases.—Dissolved gases, oxygen, nitrogen, and carbon dioxide are found in the blood. Carbonic acid (H_2CO_3) is continually entering the blood from the tissues, but the blood contains certain buffer substances, *i.e.*, sodium bicarbonate, sodium phosphate, and proteins which enter into loose combination with the carbon dioxide so that there is only about 5 per cent present in simple solution.

Endocrins.—The blood serves as a medium to carry endocrins or internal secretions.

Enzymes.—The blood serves as a medium to carry enzymes.[9]

Special substances.—Antithrombin and prothrombin are considered in connection with the clotting of blood.

Antibodies.—Under this heading are classed certain substances which help to produce *immunity*, *i.e.*, protection against diseases caused by microörganisms. Certain substances on entering the body stimulate the production of other substances to act against them. The stimulating substance (often bacteria) is called an *antigen*, and the substance that acts against it is an *antibody*. Most of the antibodies are more or less specific, *i.e.*, they only act

[8] Albumins and globulins give the same general tests; they are both coagulated by heat, and the chief difference is in their solubilities.

[9] See page 282.

against the antigens that stimulate their production. Antibodies that act against bacteria are called antibacterial, and include: (1) agglutinins, or substances which cause the bacteria (antigens) to agglutinate or clump together; (2) precipitins or substances which precipitate the bacteria from solution; (3) bacteriolysins, or substances which dissolve the bacteria. Opsonins act directly upon bacteria and belong to this class of antibodies, but their action is *not* specific. Antitoxins are substances that counteract the effect of the toxins produced by microörganisms.

THE CLOTTING OF BLOOD

Blood when drawn from the blood-vessels of a living body is perfectly fluid. In a short time it becomes viscid, and this viscidity increases rapidly until the whole mass of blood becomes a complete jelly. If the blood in this jelly stage be left untouched in a glass vessel, a few drops of an almost colorless fluid soon make their appearance on the surface of the jelly. Increasing in number and running together, the drops after a while form a superficial layer of pale straw-colored fluid. Later on, similar layers of the same fluid are seen at the sides, and finally at the bottom of the jelly, which, shrunk to a smaller size and of firmer consistency, now form a *clot*, floating in a fluid which is called *serum*, that is, blood minus the fibrin and cells. If a portion of the clot is examined under the microscope, it is seen to consist of a network of fine fibrils, in the meshes of which are entangled the red and some of the white cells of the blood. The fibrils are composed of fibrin. Many theories have been advanced to account for the formation of the insoluble fibrin, from soluble fibrinogen. The exact process is not known, but it is thought to be comparable to the clotting of milk under the influence of rennin. The essential substances are: (1) prothrombin or thrombogen, (2) calcium salts, (3) fibrinogen, and (4) tissue extract. The first three substances are in solution in the blood-plasma and tissue extract is set free by crushed tissue cells and the throm-

FIG. 123.—BOWL OF RECENTLY CLOTTED BLOOD, SHOWING THE WHOLE MASS UNIFORMLY SOLIDIFIED. (Dalton.)

FIG. 124.—BOWL OF CLOTTED BLOOD AFTER TWELVE HOURS SHOWING THE CLOT CONTRACTED AND FLOATING IN THE FLUID SERUM. (Dalton.)

bocytes which readily disintegrate when exposed to air and rough surfaces, conditions which usually result from a wound. Prothrombin may be converted to active thrombin by the action of calcium but in the circulating blood this is prevented by antithrombin, an inhibiting substance formed in the liver. This antithrombin must first be neutralized by the tissue extract, then the calcium reacts with prothrombin to form thrombin, which in turn reacts with the fibrinogen to form fibrin. The fibrils of the fibrin entangle the blood cells and form a clot. This may be represented in diagrammatic form as follows:—

Cellular elements of blood and tissues— →tissue extract.[10]
Tissue extract neutralizes antithrombin.
Prothrombin + calcium— →thrombin.
Thrombin + fibrinogen— →insoluble fibrin.
Fibrin + cells of blood— →clot.[11]

Value of clotting.—This property is of very great importance in the arrest of hemorrhage. The clot formed closes the openings of wounded vessels, and the procedures used to check hemorrhage are directed toward hastening the formation of a clot, and stimulating the blood-vessels to contract so that a smaller-sized clot will be sufficient.

The clotting power of the blood differs in different individuals and in rare cases is so slight that the most trivial operation involving hemorrhage is attended with great danger. This condition is called hemophilia.

Conditions affecting clotting.—Clotting is hastened by:—

(1) Injury to the walls of the blood-vessels.

(2) Contact with a rough surface or any foreign substance. Clotting is hastened when gauze or like substance is put into a wound.

(3) The venom of certain snakes.

(4) A temperature above 116° F. (36° C.), *e.g.*, the use of hot towels to check bleeding from the stump of an amputated limb; the use of hot douches to check postpartum hemorrhage.

(5) Rest, *e.g.*, tends to prevent the dislodgment of clots forming at the opening of vessels. If blood is contained in a dish agitation hastens the disintegration of the thrombocytes and thus favors the formation of tissue extract.

Clotting is hindered by:—

(1) Contact with the smooth lining of the heart and blood-vessels.

(2) A deficiency of the normal calcium salts.

[10] The active principle of tissue extract has been given various names, for instance, thrombokinase, cytozyme (Bordet), cephalin, etc.

[11] Other theories are also given in the more detailed works on Physiology.

(3) The addition of citrates or oxalates to the blood, because they interact with the calcium.

(4) A very low temperature. Cold hinders the formation of a clot but is often used to check hemorrhage, because it stimulates the blood-vessels to contract.

(5) A deficiency or abnormal condition of thrombocytes.

(6) Concentrated solutions of such salts as magnesium sulphate, sodium sulphate, sodium chlorid, sodium carbonate, and the bile-salts.[12]

(7) The injection into the blood of such organic ferments as pepsin, trypsin, leech extracts and the venom of certain snakes.

(8) Absence of fibrinogen.

(9) Removal of fibrin. If fresh blood, before it has time to clot, be whipped with a bundle of twigs, the fibrin will form on the twigs, and if the whipping of the blood be continued until after the fibrin has been deposited on the twigs, the blood left in the vessel will be found to have lost the power of clotting. Such blood is called **defibrinated.**

(10) If blood is received into a receptacle that is coated with oil or paraffin clotting is retarded.

Why blood does not clot within the blood-vessels.—In accordance with the theory of clotting which we have considered, blood does not clot within the blood-vessels because of: (1) the absence of tissue extract and (2) the presence of antithrombin.

Intravascular clotting.—It is well known that clots occasionally form within the blood-vessels. The most frequent causes are:—

(1) Any foreign material, even air, that is introduced into the blood and not absorbed, may stimulate the formation of thrombin and a clot.

(2) When the internal coat of a blood-vessel is injured, as for instance by a ligature, the endothelial cells are altered and may act as a foreign substance. If in addition there is a stasis of blood at this point, disintegration of the blood-platelets and white cells may result in the formation of thrombin and a clot. The products of bacteria and other toxic substances may injure the lining of a blood-vessel and produce the same result.

Thrombus and embolus.—A clot which forms inside a blood-vessel is called a thrombus and the condition is called thrombosis. A thrombus may be broken up and disappear, but the danger is that it may be carried to some point in an important vessel

[12] A person who is jaundiced, a condition due to absorption of the bile by the blood, may have a severe hemorrhage from a slight wound.

where it acts as a wedge, blocks circulation, and may cause instant death. A thrombus that becomes dislodged from its place of formation is called an embolus.

Regeneration of the blood after hemorrhage.—A large portion of the total amount of blood in the body may be lost suddenly by hemorrhage without producing a fatal result. It is probable that a healthy individual may recover from the loss of as much as three per cent of the body weight. Experiments on lower animals show that the plasma of the blood regains its normal volume within a few hours after a slight hemorrhage, and in from twenty-four to forty-eight hours if the loss of blood has been severe; but the number of red cells and hemoglobin are restored more slowly, getting back to normal after a number of days or even weeks. Blood-transfusion, *i.e.*, the transfusion of blood from one human being to another, is sometimes resorted to, and modern technic has overcome some of the difficulties[13] attending this procedure, but in cases of severe hemorrhage it is simpler to inject a physiological salt solution, *i.e.*, sodium chlorid 0.7 to 0.9 per cent, which has the same degree of concentration (isotonic) as the blood, hence does not hemolyze the red cells. The disadvantage of intravenous infusion of normal saline is that its good effects are temporary, water being rapidly lost to the tissues, rendering them edematous. Sometimes substances like gum arabic are added to make the viscidity of the saline more nearly like that of the blood.

[13] It is necessary to be sure that the blood of the donor will not have a toxic or hemolytic effect on the blood of the recipient, and clotting must be prevented.

SUMMARY

- **Vascular System**
  - **Circulating Fluids**
    - Blood
    - Lymph
  - **Systems**
    - Blood vascular.
    - Lymph vascular.

- **Blood**
  - **Description**
    - Color
      - Bright red in arteries.
      - Dark red in veins.
    - Sticky fluid.
    - Specific gravity averages about 1.055.
    - Alkaline reaction when tested with litmus.
    - Temperature, 100° F.
    - Peculiar odor. Salty taste.
    - $^1/_{20}$ of the body weight.
  - **Functions**
    - Serves as a medium for (1) the interchange of gases, (2) the interchange of nutritive and waste materials, (3) the transmission of internal secretions, (4) aids in equalizing the temperature of the body, (5) aids in equalizing the water contents of the body, and (6) aids in protecting the body from toxic substances.
  - **Composition**
    - Cells about $\frac{1}{3}$ of volume
      - Red, or erythrocytes.
      - White, or leucocytes.
      - Blood-platelets or thrombocytes.
    - Plasma, about $\frac{2}{3}$ of volume
      - Transparent, slightly yellowish fluid, containing a great variety of substances.

- **Red Cells**
  - **Description**
    - Biconcave discs about $^1/_{3200}$ in. in diameter.
    - Stroma containing hemoglobin
      - Iron salt, named hematin.
      - Protein, named globin.
    - Have no nuclei.
    - Soft, flexible, and elastic.
  - **Number**
    - Cubic millimeter of blood contains about
      - 5,000,000 for men.
      - 4,500,000 for women.
      - Varies even in health.
    - Polycythemia—increase above normal.
    - Anemia—deficiency of red cells or deficiency of hemoglobin in the cells.
  - **Function**
    - Oxygen carriers.
    - Color due to oxygen in combination with hemoglobin.
  - **Hemolysis**
    - Any destruction of the form of red cells is called hemolysis.
  - **Life Cycle**
    - Before birth—originate in liver, spleen, lymphatic tissues and bone-marrow.
    - After birth—originate in red marrow of bones.
    - Lose their nuclei before being forced into the circulation, which suggests that their term of existence is short.
    - Probably incapable of
      - Independent motion.
      - Repairing waste.
      - Reproducing.
    - Disintegrate probably in
      - Liver.
      - Lymph-nodes.
      - Spleen.

White Cells

- **Description**
  - Typical cells, containing a nucleus—sometimes two or three nuclei.
  - Variable in size, sometimes larger, sometimes smaller than red cells.
  - Gray (not white) in color.
  - Not a clearly-recognizable membrane.
- **Number**
  - Cubic millimeter of blood
    - 5000 to 7000.
    - Increase = leucocytosis.
    - Decrease = leucopenia.
- **Varieties**
  - Lymphocytes are not granular
    - (*a*) Small.
    - (*b*) Large.
  - Leucocytes are granular
    - (*a*) Polymorphonuclear or neutrophils.
    - (*b*) Eosinophils or acidophils.
    - (*c*) Mast-cells or basophils.
    - (*d*) Monocytes.
- **Functions**
  - Supposed to be different for different forms.
  1. Protect the body from bacteria.
  2. Promote tissue repair.
  3. Aid in absorption from intestines.
  4. Help in clotting of blood.
  5. Probably help to form typical blood-proteins.
- **Life Cycle**
  - Lymphocytes arise in lymph-nodes and lymph-nodules surrounding many mucous cavities.
  - Leucocytes arise from cells of bone marrow, called myelocytes.
  - Numbers lost in
    - (1) Battles against bacteria.
    - (2) Hemorrhage.
    - (3) Formation of granulation tissue.

Inflammation

- (1) Irritation resulting from injury or infection.
- (2) Increased supply of blood.
- (3) Engorgement of blood-vessels.
- (4) Migration of white cells.
- (5) Exudation of plasma.
- (6) Red cells forced through capillary walls.
- **Symptoms**
  - Pain.
  - Heat.
  - Redness.
  - Swelling.
  - Loss of function.
- **Result**
  - (*a*) Resolution—White cells eat up bacteria, clear up debris and return to blood.
  - (*b*) Suppuration—Bacteria destroy white cells and form pus.
  - (*c*) Pus consists of
    - Bacteria
      - Dead.
      - Living.
    - Phagocytes.
    - Disintegrated tissue cells.
    - Exudate from blood-vessels.

Blood-platelets or Thrombocytes

- **Description**
  - Irregularly shaped bodies of protplasm, vary in size, always smaller than red or white cells.
  - Origin, fate, and function are open questions.
  - Assist in clotting of blood.

Plasma

- Water—80 per cent.
- Blood-proteins
  - Fibrinogen.
  - Paraglobulin or scrumglobulin.
  - Serum-albumin.
- Nutrients
  - Proteins.
  - Carbohydrates.
  - Fats.
- Salts (Chlorids, Sulphates, Phosphates, Carbonates) of (Sodium, Calcium, Magnesium, Potassium, Iron) — Nutrients, wastes or regulatory substances.
- Waste Substances
  - Purin bases.[14]
  - Urea.
  - Uric Acid.
  - Creatin.
  - Creatinin.
- Gases
  - Oxygen.
  - Carbon dioxide—waste or regulatory.[15]
  - Nitrogen.
- Endocrins—see page 283.
- Enzymes—see page 282.
- Special Substances such as
  - Antithrombin.
  - Prothrombin or thrombogen.
- Antibodies
  - Agglutinins—Opsonins.
  - Precipitins—Antitoxins.
  - Bacteriolysins.

Clotting

- Serum—Blood minus fibrin and cells.
- Process
  - Cellular elements of blood and tissues— → tissue extract.
  - Tissue extract neutralizes antithrombin.
  - Prothrombin + calcium — → thrombin.
  - Thrombin + fibrinogen — → insoluble fibrin.
  - Fibrin + cells of blood — → clot.
- Value—Checks hemorrhage.
- Hastened by
  1. Injury to the walls of the vessels.
  2. Contact with a rough surface or any foreign material.
  3. The venom of certain snakes.
  4. A temperature above 116° F.
  5. Rest.
  6. Agitation.
- Hindered by
  1. Contact with smooth lining of vessels.
  2. A deficiency of the normal calcium salts.
  3. The addition of citrates or oxalates to the blood.
  4. A very low temperature.
  5. A deficiency or abnormal condition of the thrombocytes.
  6. Concentrated solutions of magnesium sulphate, sodium sulphate, sodium chlorid, sodium carbonate and the bile-salts.
  7. Injection of organic ferments.
  8. Absence of fibrinogen.
  9. Removal of fibrin.
  10. Received in vessel coated with oil or paraffin.

[14] This list is by no means complete.

[15] For Carbon dioxide as a regulatory substance see page 313.

Intravascular Clotting

- **Theory to account for rare occurrence**
  - Absence of tissue extracts.
  - Presence of antithrombin.
- **Causes**
  - Any foreign material introduced into blood and not absorbed, will stimulate clotting.
  - Injury to internal coat of blood-vessels.
- **Thrombus**—Name given to clot which forms inside vessel.
- **Embolus**
  - A thrombus that has become dislodged from place of formation.

Regeneration of blood after hemorrhage

- Plasma is regenerated rapidly, red cells within a few days or weeks.

CHAPTER XI

THE BLOOD VASCULAR SYSTEM

The blood is contained in branched tubes named blood-vessels. It is driven along these tubes by the action of the *heart*, which is a hollow muscular organ placed in the center of the vascular system. One set of vessels—the *arteries*—conducts the blood out from the heart and distributes it to the different parts of the body, whilst other vessels—the *veins*—bring it back to the heart again. The blood from the arteries gets into the veins by passing through a network of fine tubes which connect the two, and which are named, on account of their small size, the *capillary* (*i.e.*, hair-like) vessels.[1]

HEART

The heart is a hollow, muscular organ, situated in the thorax between the lungs, and above the central depression of the diaphragm. It is about the size of the closed fist, shaped like a blunt cone, and so suspended by the great vessels that the broader end or base is directed upward, backward, and to the right. The pointed end or apex points downward, forward, and to the left. As placed in the body, it has a very oblique position, and the right side is almost in front of the left. The impulse of the heart against the chest wall is felt in the space between the fifth and sixth ribs, a little below the left nipple, and about 3 in. (8 cm.) to the left of the median line.

Myocardium.—The main substance of the heart is composed of muscular tissue and is called *myocardium*.[2]

Pericardium.—The heart is covered by a membranous sac called the pericardium (around the heart). It consists of two parts: (1) an external fibrous portion, and (2) an internal serous portion.

(1) The **external fibrous** pericardium is composed of white fibrous tissue, and is attached by its upper surface to the large blood-vessels which emerge from the heart. It covers these vessels for about an inch and a half (3.8 cm.) and blends with their sheaths. The lower border is firmly adherent to the dia-

[1] See table in summary. [2] See page 77.

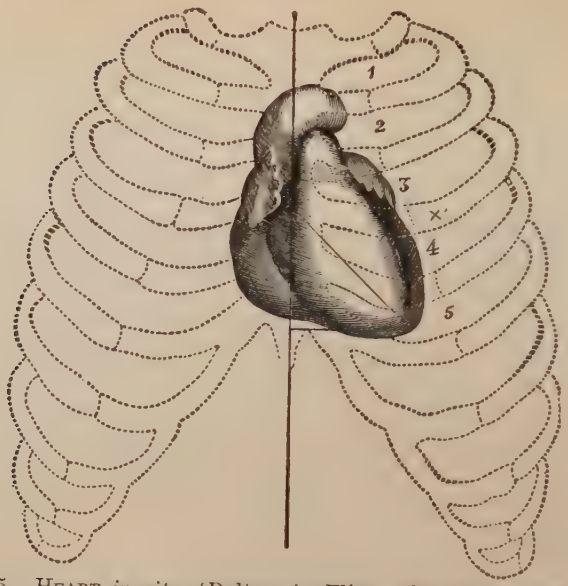


Fig. 125.—Heart *in situ* (Dalton, in Flint, "On the Heart"). 1, 2, 3, 4, 5, intercostal spaces; vertical line, median line; triangle, superficial cardiac region; × on the fourth rib, nipple.

phragm, and the front surface is attached to the sternum by means of fibrous bands.

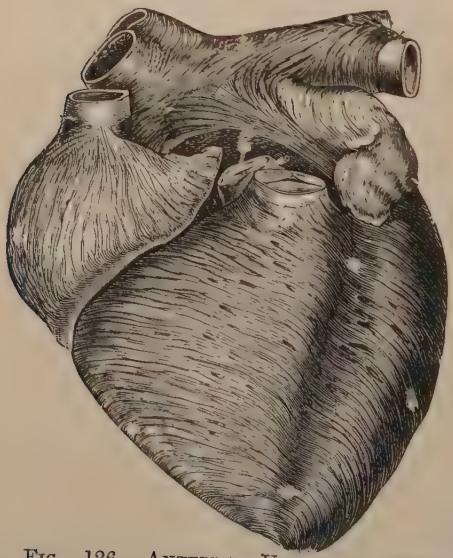


Fig. 126.—Anterior View of Heart, Dissected, after Long Boiling, to Show the Superficial Muscles of the Myocardium. The arrangement of the muscles is very intricate; they run transversely, longitudinally, obliquely, and in the apex take a spiral turn or twist. (Quain.)

(2) The **internal or serous portion** of the pericardium is a completely closed sac; it envelops the heart and lines the **fibrous** pericardium. The heart, however, is not within the cavity of the closed sac. (See Fig. 128.) That portion of the serous pericardium which lines and is closely adherent to the heart is called the visceral portion (*viscus*, organ); the remaining part of the serous pericardium, namely, that which lines

the fibrous pericardium, is known as the parietal portion (*paries*, a wall). The cavity of the serous pericardium contains a small quantity of serous liquid. Its opposed surfaces are lined by endothelium and are very smooth and polished. Owing to the constant contractions of the heart the opposing surfaces are continually sliding one upon the other, and are admirably constructed to prevent friction.

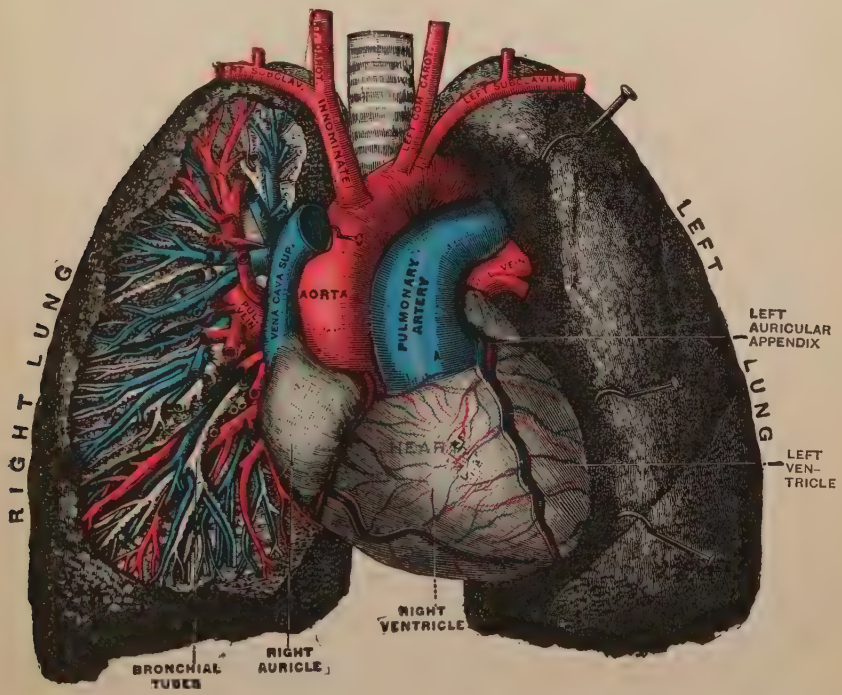


FIG. 127.—THE PULMONARY ARTERY AND AORTA. The front part of the right lung has been removed, and the pulmonary vessels and the bronchial tubes are thus exposed. See page 221. (Gerrish.)

Endocardium.—The interior of the heart is lined by a smooth, delicate membrane, called the endocardium. This pavement membrane (endothelium) lines all the cavities of the heart, and is continued into the blood-vessels, forming their innermost coat.

The cavities of the heart.—The heart is divided from the base to the apex, by a fixed partition, into a right and left half, frequently called right and left heart. The two sides of the heart have no communication with each other after birth. The right

side always contains *venous*, and the left side *arterial*, blood. Each half is subdivided into two cavities, the upper, called *auricle* (atrium); the lower, *ventricle* (ventriculum). If we examine these cavities, we notice that the muscular walls of the auricles are much thinner than those of the ventricles, and the wall of the left ventricle is thicker than that of the right (the proportion being as 3 to 1). This difference in bulk is to be accounted for, as we shall see later on, by the greater amount of work the ventricles, as compared with the auricles, have to do. These cavities communicate with one another by means of constricted openings, the auriculoventricular orifices,[3] which are strengthened by fibrous rings and protected by valves.

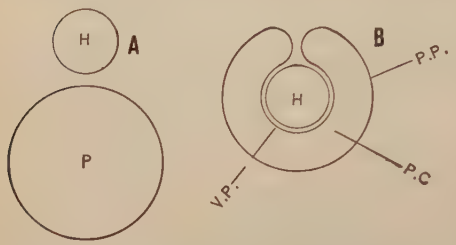


FIG. 128.—DIAGRAM OF THE HEART AND SEROUS PERICARDIUM. *A* shows heart and pericardium lying separately. *B* shows the pericardium invaginated by the heart. *V. P.* shows visceral layer that clings close to the heart muscle. *P. P.* shows parietal layer that lines the fibrous pericardium. *P. C.*, pericardial cavity which in actual conditions is a very narrow space filled with pericardial fluid.

Important orifices of the heart.—Eight large blood-vessels are connected with the heart. These eight orifices plus the two between the auricles and ventricles, make a total of ten.

On the right side of the heart, the superior and inferior vena cava empty into the auricle, and the pulmonary artery leaves the ventricle.

On the left side of the heart, four pulmonary veins empty into the auricle, and the aorta leaves the ventricle. There are some smaller openings to receive blood directly from the heart substance, and before birth there is an opening between the right and left auricle called the *foramen ovale*. Normally this closes as soon as the infant breathes.

Valves of the heart.—The auriculoventricular orifices and the openings into the aorta and pulmonary artery are guarded by valves.

The tricuspid valve.—The valve guarding the right auriculoventricular opening is composed of three irregular-shaped flaps, or cusps, and hence is named tricuspid. The flaps are mainly formed of fibrous tissue covered by endocardium. At their bases

[3] Also called atrioventricular.

they are continuous with one another, and form a ring-shaped membrane around the margin of the auricular opening: their pointed ends are directed downward, and are attached by cords, the *chordæ tendineæ*, to little muscular pillars, the *papillary muscles* in the interior of the ventricles.

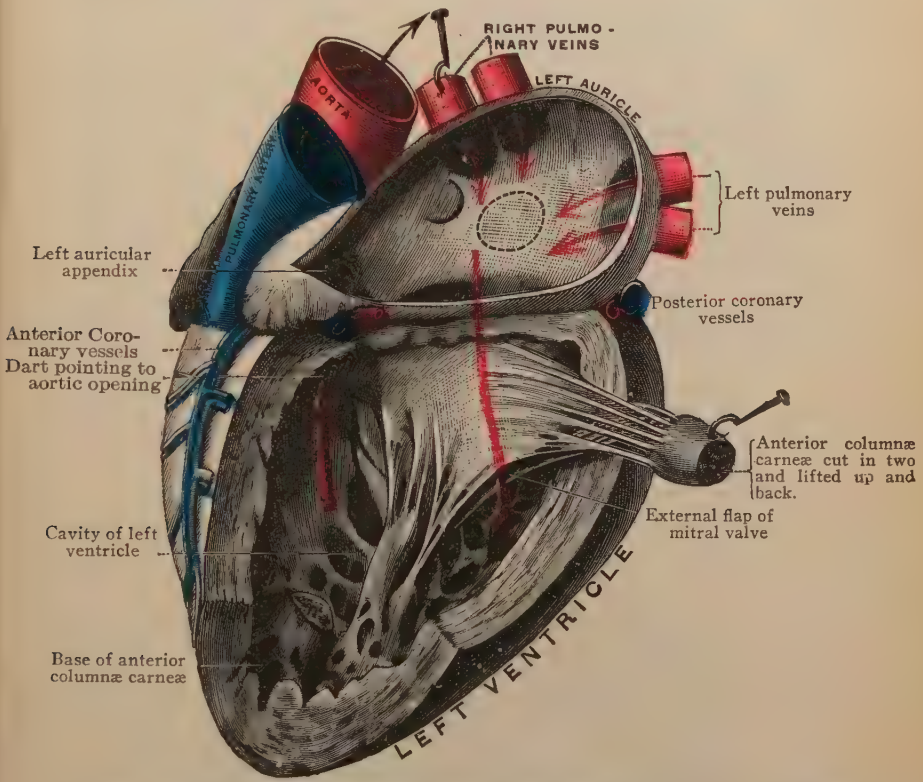


FIG. 129.—LEFT AURICLE AND VENTRICLE, THE HIND WALL OF EACH HAVING BEEN REMOVED. The columnæ carneæ are muscle columns which project from nearly the whole of the inner surface of the ventricles. Some of them give origin to the papillary muscles. (Gerrish.)

The bicuspid valve.—The valve guarding the left auricular opening consists of only two flaps or cusps, and is named the bicuspid, or mitral valve. It is attached in the same manner as the tricuspid valve, which it closely resembles in structure, except that it is much stronger and thicker in all its parts.

Function.—These valves oppose no obstacle to the passage of the blood from the auricles into the ventricles because the free edges of the flaps are pointed in the direction of the blood current; but any flow forced backward gets between the flaps and

the wall of the ventricle, and drives the flaps upward, until, meeting at their edges, they unite and form a complete transverse partition between the ventricle and auricle. Being retained by the chordæ tendineæ, the expanded flaps of the valve resist any pressure of the blood which might otherwise force them to open into the auricle; at the same time the papillary muscles, to which the chordæ tendineæ are attached, contract and shorten, thus keeping them taut.

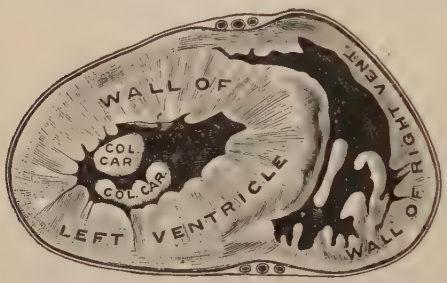


Fig. 130.—Cross-section through Both Ventricles, Showing the Shape of Their Cavities and the Relative Thickness of their Walls. (Gerrish.)

Semilunar valves.—The valves between the ventricles and arteries are called the semilunar valves (*aortic and pulmonary.*) These valves consist of three half-moon-shaped pockets, each

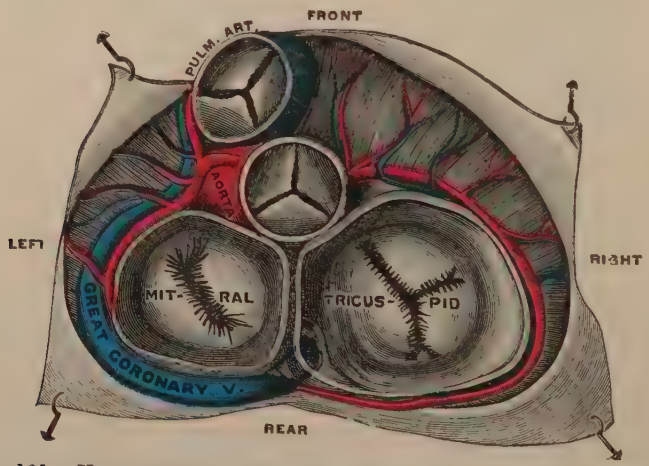


Fig. 131.—Valves of the Heart and Great Arteries, Viewed from Above, the Auricles having been Removed. (Gerrish.)

pocket being attached by its convex border to the inside of the artery where it joins the ventricle, while its other border projects into the interior of the vessel. Small nodular bodies, called the *corpora Arantii*, are attached to the center of the free edge of each pocket.

Function.—These valves offer no resistance to the passage of blood from the heart into the arteries, as the free borders project into the arteries, but they form a complete barrier to the passage of blood in the opposite direction. In this case each pocket becomes filled with blood, and the free borders are floated out and distended so that they meet in the center of the vessel. The *corpora Arantii* assist in the closure of these valves and help to make the barrier perfect.

The orifices of the heart which open into veins are not pro-

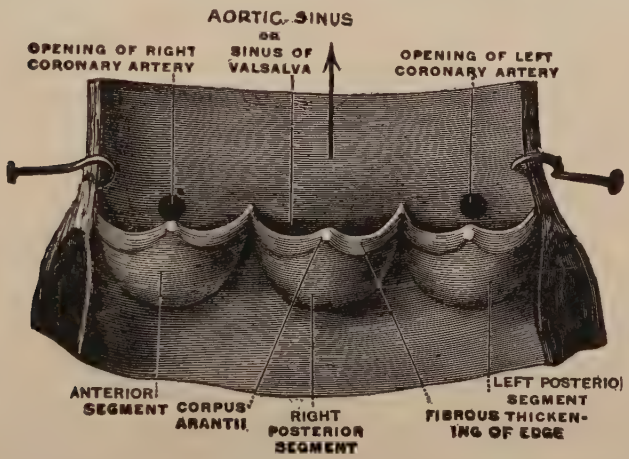


FIG. 132.—AORTIC VALVE. The artery has been cut open between the anterior and left posterior segments, and spread out. (Gerrish.)

tected by valves, with the possible exception of the opening into the inferior vena cava which is partly covered by a membrane known as the Eustachian valve.

Auriculoventricular bundle of His.—The muscular tissue of the auricles is not continuous with that of the ventricles. They are connected by fibrous tissue and the auriculoventricular bundle of His, which consists of muscular and nervous tissue. This bundle arises in two small collections of spindle-shaped cells called the sinu-auricular and auriculoventricular nodes. The sinu-auricular node is situated on the anterior border of the opening of the superior vena cava;[4] from it strands of fibers run under the endocardium of the wall of the auricle to the auriculoventricular node which lies near the origin of the coronary sinus in the right auricle. From here the bundle of fibers passes down the septum between the auricles to the septum between the ventricles where it divides into right and left bundles, one for each

[4] See page 235.

ventricle. In the lower part of the ventricles each bundle separates into numerous strands which spread over the entire internal surface. The significance of these structures is discussed on page 246.

Blood supply.—Just after the aorta leaves the left ventricle it gives off two small branches, called the *right* and *left coronary* arteries. They encircle the heart like a crown, hence their name. They supply the substance of the heart with blood, as the blood contained within the cavities of the heart only nourishes the endocardium. The blood from the coronary arteries is returned by a coronary vein to the right auricle.

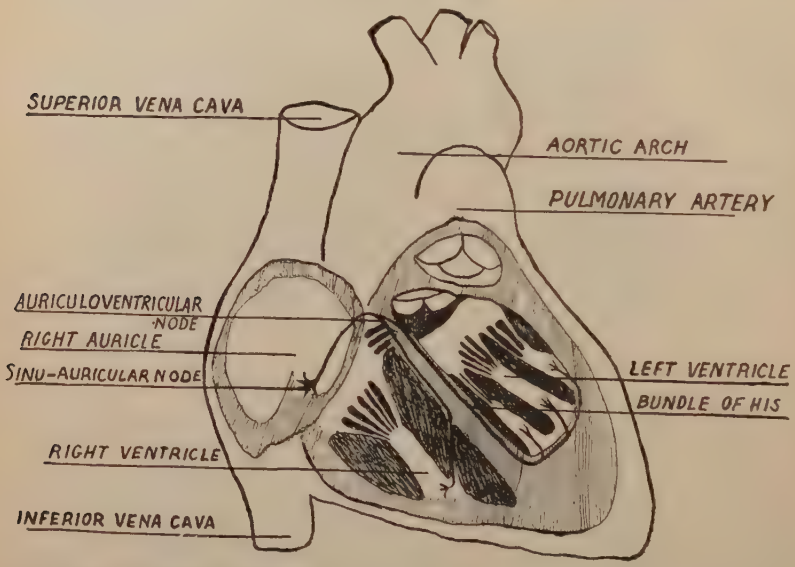


FIG. 133.—DIAGRAM OF THE AURICULOVENTRICULAR NODE AND BUNDLE OF HIS.

Nerve supply.—The heart is supplied (1) by the vagi nerves[5] from the central nervous system and (2) by nerves from the sympathetic portion of the autonomic system. Stimulation of the vagi fibers slows the action of the heart. They are therefore known as cardiac inhibitors and serve as a "brake." Stimulation of the cardiac sympathetic nerves increases the force of the heart beat, therefore they are known as cardiac accelerators.

ARTERIES

The arteries are tubes that carry blood from the heart and break up into capillaries. They are composed of three coats:—

[5] See pages 154 and 249.

1. An inner **endothelial** lining which is continuous with the endothelium lining the heart.

2. A middle coat of **muscular** and **elastic tissue.** The muscular tissue consists of fine bundles of plain muscle fibers arranged in layers and circularly disposed around the vessel. In the large arteries elastic fibers form layers which alternate with the layers of muscle fibers. By virtue of the structure of the middle coat, the arteries are both extensile and elastic.[6] The proper functioning of the arteries depends upon their extensibility and elasticity and may be demonstrated by the following example:—

If we tie a piece of a large artery at one end and inject fluid into the other end, the artery swells out to a very great extent, but will return at once to its former size when the fluid is let out.

The great extensibility and elasticity of the arteries adapt

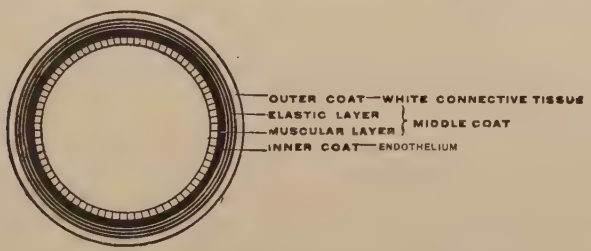


FIG. 134.—DIAGRAM OF A CROSS-SECTION OF AN ARTERY, SHOWING THE COMPOSITION OF ITS TUNICS. (Gerrish.)

them for receiving the additional amount of blood thrown into them at each contraction of the heart.

3. An outer coat of white **connective tissue** and in all but the smallest arteries some elastic tissue is found. The strength of an artery depends largely upon the outer coat; it is far less easily cut or torn than the other coats, and serves to resist undue expansion of the vessel.

The arteries do not *collapse* when empty, and when an artery is severed the orifice remains open. The muscular coat, however, contracts somewhat in the neighborhood of the opening, and the elastic fibers cause the artery to retract a little within its sheath, so as to diminish its caliber and permit a blood-clot to plug the orifice. This property of the severed artery is an important factor in the arrest of hemorrhage.

Blood and nerve supply of the arteries.—The blood which flows through the arteries nourishes only the inner coat. The

[6] It is well to bear in mind the difference between extensile and elastic. By extensile we mean that an object can be stretched; by elastic that it returns to its former shape as soon as the stretching force is removed.

external coat is supplied with arteries, capillaries, and veins, called **vasa vasorum,** or blood-vessels of the blood-vessels.

The muscular tissue found in the walls of the arteries is supplied with nerves chiefly from the autonomic system. These nerves are called **vasomotor,** and are divided into two sets, (1) vasoconstrictor, and (2) vasodilator. They connect with the vasoconstrictor center[7] which is constantly sending impulses to the vessels, thus keeping them in a state of tone. The vasoconstrictor center is a reflex center, and is connected with afferent fibers coming from all parts of the body. Some of the arteries are supplied with vasodilator fibers, which when stimulated inhibit the action of the vasoconstrictors and cause dilatation of the vessels. The widening and narrowing of the arteries not only affect the local circulation in different parts of the body, but the amount of resistance they oppose to the arterial impulse also influences in some degree the character of the heart beat.

Sheaths of the arteries.—The greater number of the arteries are accompanied by a nerve and one or two veins and surrounded by a sheath of connective tissue, which helps to support and hold these structures in position.

Size of the arteries.—The largest arteries in the body, the aorta and pulmonary artery, measure more than one inch (3 cm.) in diameter, at their connection with the heart. These arteries give off branches, which divide and subdivide into smaller branches. A branch of an artery is always less than the trunk from which it springs, hence the arteries grow smaller as they subdivide, and gradually lose their characteristic structure. The smallest arteries are called *arterioles,* and at their distal ends, where only the internal coat remains, the capillaries begin.

CAPILLARIES

The capillaries are exceedingly minute vessels which average about 8 microns (0.008 mm.) in diameter. They connect the arterioles (smallest arteries) with the venules (smallest veins), thus receiving the blood from the arterioles and carrying it to the venules.

Structure.—The walls of the capillaries are formed entirely of *one* layer of simple endothelium composed of flattened cells joined edge to edge by cement substance, and continuous with the layer which lines the arteries and veins.

Distribution.—The capillaries communicate freely with one another and form interlacing networks of variable form and size in the different tissues. All the tissues, with the exception of the

[7] See page 154.

cartilages, hair, nails, cuticle, and cornea of the eye,[8] are traversed by these networks of capillary vessels. Their diameter is so small that the blood cells must pass through them in single file and very frequently the cell is larger than the caliber of the vessel, and has to be squeezed to enable it to pass through. In many parts they lie so closely together that a pin's point cannot be inserted between them. They are most abundant, and form the finest net works, in those organs where the blood is needed for purposes other than local nutrition, as, for example, secretion or absorption.

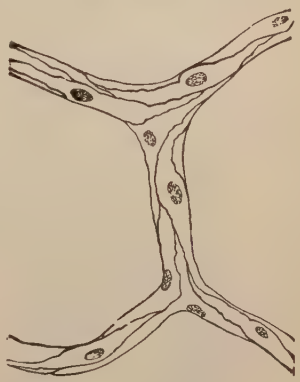


FIG. 135.—FINE CAPILLARIES FROM THE MESENTERY. (Collins.)

Function.—In the glandular organs the capillaries supply the substances requisite for secretion; in the alimentary canal they take up some of the elements of digested food; in the lungs they absorb oxygen and give up carbon dioxide; in the kidneys they discharge the waste products collected from other parts; all the time, everywhere through their walls, that interchange is going on which is essential to the renovation and life of the whole body. It is in the capillaries, then, that the chief work of the blood is done; and the object of the vascular mechanism is to cause the blood to flow through these vessels in the manner best adapted for accomplishing this work.

VEINS

The veins are tubes that carry blood to the heart, and are made by the gathering together of the capillaries. They have three coats and on the whole resemble the arteries in structure. They differ from them in having: (1) much thinner walls (see Fig. 136); (2) they contain less elastic tissue, hence are not so elastic or contractile as the arteries; (3) many of the veins are provided with valves.

Valves.—The valves are semilunar folds of the internal coat of the veins; and usually consist of two flaps, rarely one or three. The convex border is attached to the side of the vein, and the free edge points toward the heart. Their function is to prevent

[8] These parts not penetrated by the blood-vessels imbibe nutritive matter from adjacent tissues, and are just as dependent on the blood as all the other tissues.

reflux of the blood and keep it flowing in the right direction, *i.e.*, toward the heart.

If for any reason the blood on its onward course toward the heart is driven backward, the refluent blood, getting between the wall of the vein and the flaps of the valve, will press them inward until their edges meet in the middle of the channel and close it. The valves are most numerous in the veins where reflux is most likely to occur, *i.e.*, the veins of the extremities. For the same reason a greater number are found in the lower than in the upper limbs. They are absent in many of the small veins, in the large veins of the trunk, and in veins not subjected to muscular pressure. The veins, like the arteries, are supplied with both blood-vessels and nerves; the supply, however, is far less abundant.

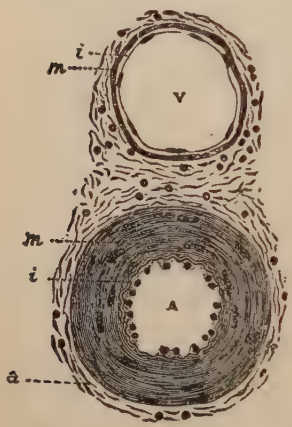


FIG. 136. — TRANSVERSE SECTION THROUGH A SMALL ARTERY AND VEIN, SHOWING THE RELATIVE DIFFERENCE IN THE THICKNESS OF THEIR WALLS. *A*, Artery showing *i*, the endothelial lining which with the thin layer of elastic tissue next to it constitutes the *intima*. The endothelial cells appear thick because the artery is contracted. *m*, the circular muscular coat or *media* constitutes the chief part of the wall of the vessel. Outside this is *a*, part of the outer coat or *adventitia*. *V*, Vein showing *i*, a thin endothelial membrane, *m*, a few circular muscle cells.

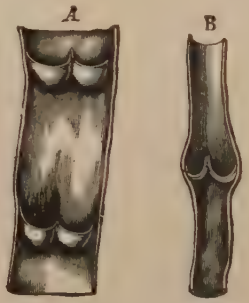


FIG. 137.—DIAGRAM SHOWING VALVES OF VEINS. *A*, part of a vein, laid open, with two pairs of valves; *B*, longitudinal section of vein, showing valves closed. (Sharpey.)

It must be remembered that although the arteries, capillaries, and veins have each the distinctive structure above described, it is difficult to draw the line between the arteriole and large capillary; and between the large capillary and venule. The veins on leaving the capillary networks only gradually assume their several coats, while the arteries dispense with their coats in the same imperceptible way as they approach the capillaries.

SUMMARY

HEART

- **Blood Vascular System**
  - Heart.
  - Arteries—small arteries are named arterioles.
  - Capillaries.
  - Veins—small veins are named venules.
- **Location**
  - Between lungs
  - Above diaphragm.
- **Structure**
  - Smooth lining on inside—*Endocardium.*
  - Muscle substance—*Myocardium.*
  - Outside covering—*Pericardium*
    - Fibrous portion.
    - Serous
      - Visceral.
      - Parietal.
- **Cavities**
  - **Right heart**
    - **Right auricle**
      - Receives blood.
      - Thin walls.
    - **Right ventricle**
      - Expels blood into pulmonary artery.
      - Thick walls.
  - **Left heart**
    - **Left auricle**
      - Receives blood.
      - Thin walls.
    - **Left ventricle**
      - Expels blood into aorta.
      - Very thick walls.
- **Orifices**
  - **Right heart**
    - **Right auricle**
      - Superior vena cava—returns blood from upper portion of body.
      - Inferior vena cava—returns blood from lower portion of body.
    - Auriculoventricular orifice between auricle and ventricle.
    - **Right ventricle**
      - Pulmonary artery—carries blood from heart to lungs.
  - **Left heart**
    - **Left auricle**
      - Two right pulmonary veins
      - Two left pulmonary veins
      - Return blood from lungs.
    - Auriculoventricular orifice between auricle and ventricle.
    - **Left ventricle**
      - Aorta—distributes blood to all parts of the body.
- **Valves**
  - **Tricuspid valve**—composed of three cusps situated in the right ventricle.
  - **Bicuspid or mitral valve**—composed of two strong, thick cusps situated in the left ventricle.
  - **Function**—Prevent flow of blood from ventricles into auricles.
  - **Semilunar valves**
    - **Aortic** — composed of three half-moon-shaped pockets between aorta and left ventricle.
    - **Pulmonary**—composed of three half-moon-shaped pockets between pulmonary artery and right ventricle.
    - **Function**—Prevent flow of blood from arteries into ventricles.
- **Auriculoventricular bundle of His**—Bundle of muscular and nervous tissue located in septum between right and left heart, which connects the musculature of auricles and ventricles.
- **Nerve Supply**
  - **Central nervous system**—Vagi nerves, *inhibitory fibers,* slow the heart.
  - **Autonomic system**—*Accelerator fibers* increase rapidity and force of heart.
- **Blood Supply**
  - Right coronary artery
  - Left coronary artery
  - branches from aorta.

Arteries — Characterized by elasticity
- **Hollow tubes**—Carry blood *from* heart, break up into capillaries.
- **Coats**
  1. Endothelial lining.
  2. Muscular and elastic tissue.
  3. Connective tissue.
- **Sheaths**—outside covering of connective tissue which surrounds the arteries.
- **Size**—Aorta more than one inch in diameter. Arteries grow smaller as they subdivide. Smallest ones are microscopic and are called **arterioles.**

Capillaries — Characterized by multiplicity
- **Tiny tubes**—about 8μ in diameter. Connect arterioles and venules.
- One coat of simple endothelium.
- Communicate freely—form networks.

Veins — Characterized by valves
- **Collapsible tubes**—smallest ones, called venules, begin where capillaries end.
- Carry blood to heart.
- Three coats, same as arteries but thinner.
- Valves—semilunar pockets.

Vasa vasorum—The term applied to blood-vessels that are supplied to coats of other blood-vessels.

Vasomotor—Term applied to *nerves* supplied to blood-vessels
- Vasoconstrictor.
- Vasodilator.

CHAPTER XII

THE BLOOD VASCULAR SYSTEM CONTINUED: ARTERIES; PULMONARY SYSTEM; GENERAL SYSTEM; VEINS; SUPPLEMENTARY CHANNEL, AND ACCESSORY OR PORTAL SYSTEM

The arteries, which carry and regulate the supply of blood from the heart to the capillaries, are distributed throughout the body in a systematic manner, and before attempting the study of the

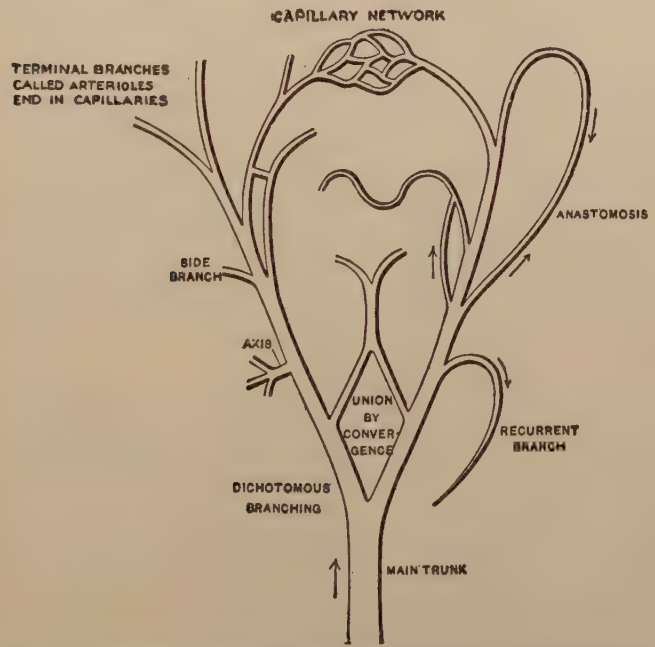


FIG. 138.—DIAGRAM SHOWING THE BRANCHINGS, ANASTOMOSES, AND CONFLUENCE OF ARTERIES. (Gerrish.)

circulation, we must try to gain a general idea of this system of distribution, in order that we may be able to locate the position of these important vessels. The arteries usually occupy *protected* situations, that they may be exposed as little as possible to accidental injury, or to the effects of local pressure.

Division.—As they proceed in their course they divide into branches, the division taking place in different ways.

(1) An artery may at once resolve itself into two branches of nearly equal size (dichotomous division, or splitting in two).

(2) It may give off several branches in succession and still maintain its character as a trunk.

(3) It may give off one branch that divides into several branches at the same point, *e.g.*, the celiac artery.

Anastomosis or inosculation.—The distal ends of arteries unite at frequent intervals, when they are said to anastomose, or inosculate. Such inosculations admit of free communication between the currents of the blood, tend to obviate the effects of local interruption, and to promote equality of distribution and of pressure. This arrangement makes it possible to tie veins and arteries during operations, or after injuries, without serious interference with the circulation.

Plexus.—A plexus or network is formed by the inosculations of a number of arteries in a limited area. Arteries usually pursue a tolerably straight course, but in some parts of the body they are tortuous. The *facial* artery, in its course over the face, and the arteries of the lips are extremely tortuous, so that they may accommodate themselves to the movements of the parts.

Divisions of the vascular system.—The blood-vessels of the body are arranged in two main systems, namely, the pulmonary and the general or systemic.

THE PULMONARY SYSTEM

The pulmonary system is the lesser system and provides for the circulation of the blood from the right ventricle to the lungs, and then back to the left auricle. This is called the pulmonary circulation.

Blood-vessels of the pulmonary system.—The blood-vessels of the pulmonary system are (1) the pulmonary artery and all its branches, (2) the capillaries which connect these branches with the veins, and (3) the pulmonary veins.

The pulmonary artery.—The pulmonary artery conveys the venous blood from the right side of the heart to the lungs. The main trunk is a short, wide vessel about two inches (5 cm.) in length and a little more than one inch (about 3 cm.) in diameter. It arises from the right ventricle, in front of the aorta, and passes for a distance of two inches (5 cm.) upward, backward, and to the left. (See Fig. 127.) On a level with the intervertebral disc, between the fifth and sixth thoracic vertebræ, it divides into two branches, the right and left pulmonary arteries, which pass to the

right and left lungs. From these main branches, arteries arise which divide and subdivide, grow smaller in size, and finally

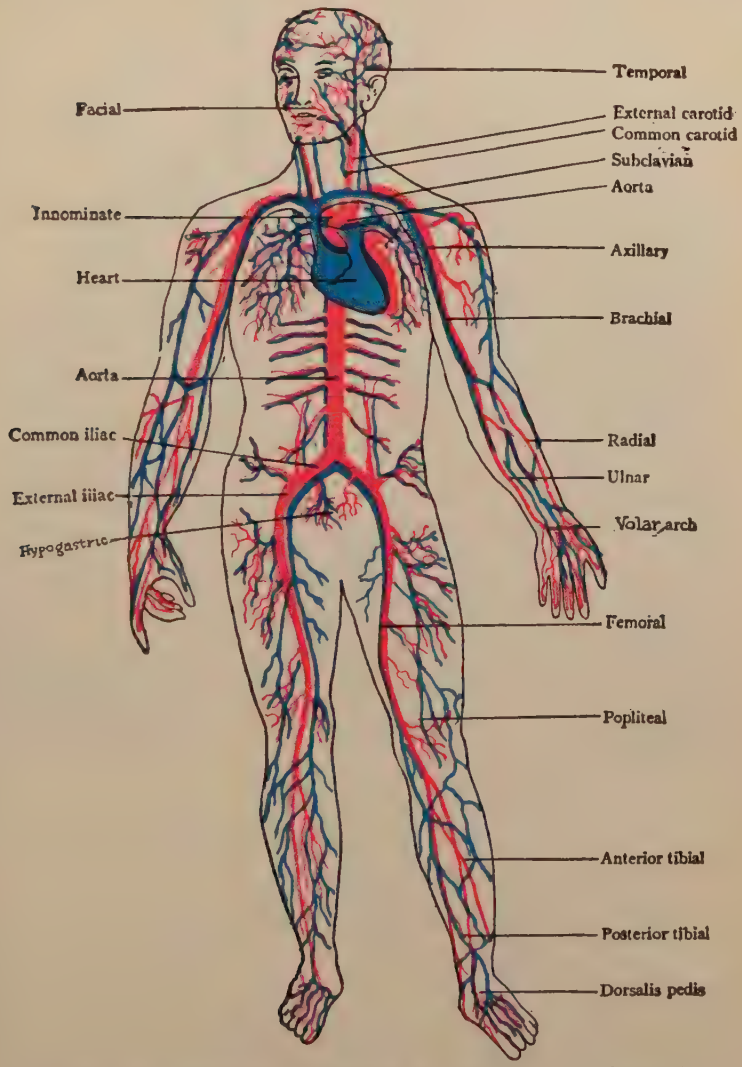


FIG. 139.—THE PRINCIPAL ARTERIES OF THE BODY. (MORROW.)

merge into capillaries which form a network upon the walls of the air cells.[1] These capillaries unite, grow larger in size, and gradually assume the characteristics of veins. The veins unite to form the pulmonary veins.

[1] See page 307.

The pulmonary veins.—The pulmonary veins are four short trunks which convey the blood from the lungs to the left auricle, and are found, two on each side,—in the root of the corresponding lung. The pulmonary veins have no valves.

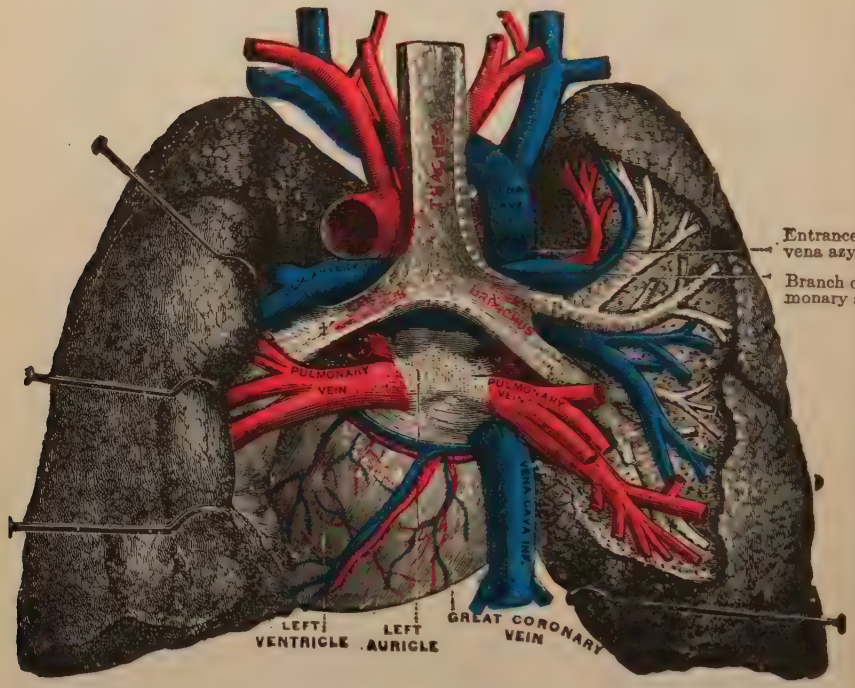


FIG. 140.—PULMONARY VESSELS, SEEN IN A DORSAL VIEW OF THE HEART AND LUNGS. The left lung is pulled to the left, and the right lung has been partly cut away to show the ramifications of the air tubes and blood-vessels. (Gerrish.)

THE GENERAL SYSTEM

The general system is the larger system and provides for the circulation of blood from the left ventricle to all parts of the body by means of the aorta and its branches and the return to the right auricle by means of the venæ cavæ. This is called the systemic circulation.

The blood-vessels of the general system.—The blood-vessels of the general system consist of (1) the *aorta*, and all the arteries that originate from it, including the terminal branches called arterioles; (2) the capillaries which connect the arterioles and venules; (3) all the venules and veins of the body which empty

either directly into the heart, or indirectly by means of the superior and inferior venæ cavæ.

The aorta.—The aorta is the main trunk of the arterial system. Springing from the left ventricle of the heart, it arches over the root of the left lung, descends along the vertebral column, and after passing through the diaphragm into the abdominal cavity, ends opposite the fourth lumbar vertebra by dividing into the right and left common iliac arteries. In this course the aorta forms a continuous trunk, which gradually diminishes in size from its commencement to its termination. It gives off large and small branches at various points.

FIG. 141.—THORACIC AORTA. (Gerrish.)

It may be divided as follows: (1) the **ascending aorta** is the short part about 2 inches or 5 cm. which is contained within the pericardium.

(2) The **arch** extends from the ascending aorta upward, backward and to the left in front of the trachea, then backward and downward on the left side of the body of the fourth thoracic vertebra where it becomes continuous with the descending aorta.

(3) The **descending thoracic aorta** is the comparatively straight part that extends from the lower border of the fourth thoracic vertebra on the left side, to the aortic opening in the diaphragm in front of the lower border of the last thoracic vertebra.

(4) The **abdominal aorta** commences at the aortic opening of

the diaphragm, in front of the lower border of the last thoracic vertebra, and terminates below by dividing into the two common

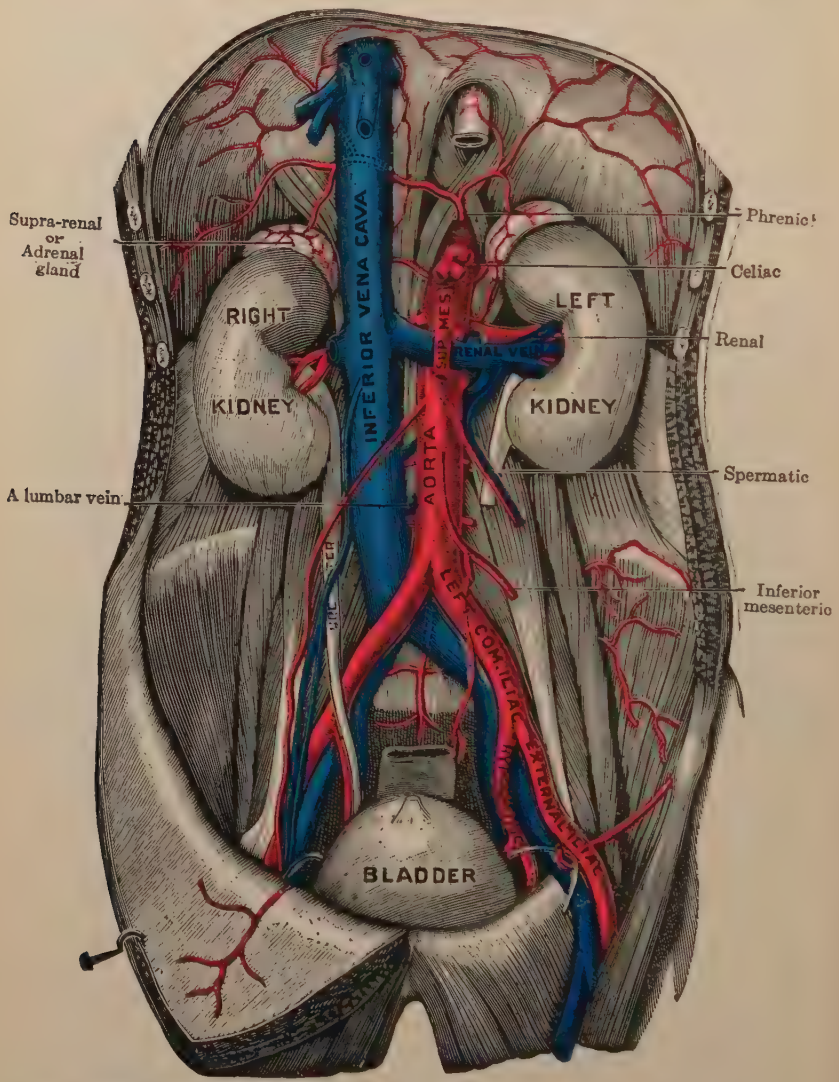


FIG. 142.—THE ABDOMINAL AORTA AND INFERIOR VENA CAVA. (Gerrish.)

iliac arteries. The bifurcation usually takes place about halfway down the body of the fourth lumbar vertebra, which corresponds to a spot on the front of the abdomen, slightly below and to the left of the umbilicus.

Branches of the ascending aorta.—The only branches of the ascending aorta are the right and left coronary arteries. They arise immediately above the semilunar valves and encircle the heart, giving off numerous branches that supply the heart muscle. (See Fig. 132.)

Branches of the arch of the aorta.—The branches given off from the arch of the aorta are three in number—the innominate,

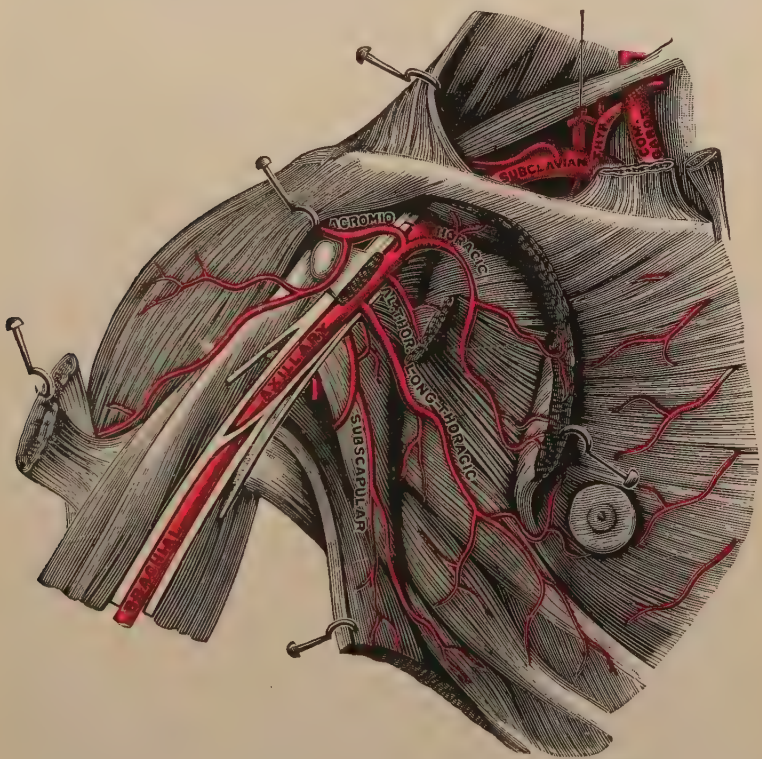


FIG. 143.—SUBCLAVIAN AND AXILLARY ARTERIES. (Gerrish.)

the left common carotid, and the left subclavian arteries. (See Fig. 127.)

The **innominate** (brachiocephalic) artery arises from the right upper surface of the arch, ascends obliquely toward the right, until, arriving on a level with the upper margin of the clavicle, it divides into the right common carotid and right subclavian arteries. (See Fig. 127.)

The **left common carotid** arises from the middle of the upper surface of the arch of the aorta, and the right common carotid arises at the division of the innominate, consequently the left

carotid is an inch or two longer than the right. They ascend obliquely on either side of the neck until, on a level with the upper border of the thyroid cartilage (Adam's Apple), they divide into two great branches: (1) the external carotid, (2) the internal carotid. At the root of the neck the common carotids are separated from each other by only a narrow interval, corresponding with the width of the trachea; but at the upper part,

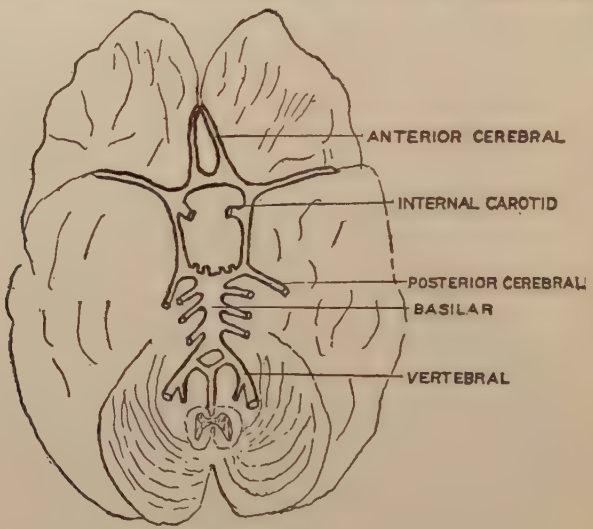


Fig. 144.—Diagram of the Circle of Willis.

the thyroid gland, the larynx and pharynx project forward between them.

Each **external carotid** has eight branches, which are distributed to the throat, tongue, face, ears, and walls of the cranium.

Each **internal carotid** has many branches which are distributed to the brain, the eye and its appendages, the forehead and nose. Two important ones are the **cerebral** and **ophthalmic.**

Circle of Willis.—This is a remarkable anastomosis formed by the blood-vessels of the brain. It is situated at the base of the brain and is formed by the union of (1) the anterior cerebral arteries, which are branches of the internal carotid, and (2) the posterior cerebral arteries which are branches of the basilar artery. The basilar is formed by the union of the two vertebrals.[2] These arteries are joined in such a manner as to form a complete circle, and this arrangement (1) equalizes the circulation of the

[2] The vertebral arteries are branches given off from the subclavian. They ascend on either side of the vertebral column, pass through the foramen magnum, and at the base of the brain unite to form the *basilar* artery.

blood in the brain, and (2) in case of destruction of one of the arteries, provides for the blood reaching the brain through other vessels.

The subclavian arteries.—The right subclavian arises at the division of the innominate, and the left subclavian from the arch of the aorta. The subclavian arteries are the first portions of a long trunk which forms the main artery of the upper limb, and which is artificially divided for purposes of description into three parts; *viz.*: (1) subclavian, (2) axillary, and (3) brachial.

The **subclavian** artery passes a short way up the thorax into the neck, and then turns downward to rest on the first rib. At the lower border of the first rib it ceases to be called subclavian, and is continued as the axillary. It gives off large branches to the brain, back, chest, and neck.

The **axillary** artery passes through the axilla, lying to the inner side of the shoulder joint and upper part of the arm. It gives off branches to the chest, shoulder, and arm.

The **brachial** artery (continuation of the axillary) extends from the end of the axillary artery to just below the bend of the elbow, where it divides into the ulnar and radial arteries. It may be located, lying in the depression along the inner border of the biceps muscle. Pressure made at this point from within outward against the humerus will control the blood-supply to the arm.

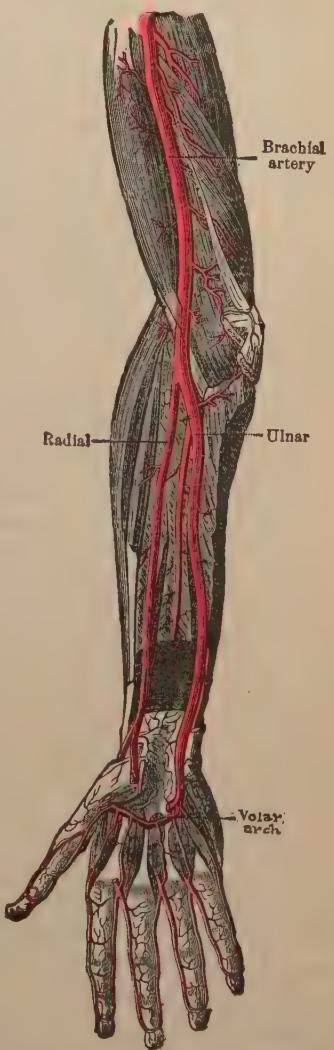


FIG. 145.—DEEP ANTERIOR VIEW OF THE ARTERIES OF THE ARM, FOREARM, AND HAND.

The **ulnar,** the larger of the two vessels into which the brachial divides, extends along the little finger side of the forearm into the palm of the hand, where it divides into the branches which enter

into the formation of the superficial and deep volar arches (palmar arches).

The **radial** artery appears, by its direction, to be a continuation of the brachial, although it does not equal the ulnar in size. It extends along the thumb side of the forearm as far as the lower end of the radius, below which it turns around the outer border of the wrist, and passes forward into the palm of the hand, where it unites with the deep volar branch of the ulnar artery to form the deep volar arch. The superficial and deep volar arches anastomose and supply the hand with blood.

Branches of the thoracic aorta.—The branches derived from the thoracic aorta are numerous but small, and the consequent decrease in size is not marked. They may be divided into two sets:—

Visceral, or those which supply the viscera.

Parietal, or those which supply the walls of the chest cavity.

The **visceral group** includes (1) the pericardial, (2) the bronchial, (3) the esophageal, and (4) the mediastinal.

(1) The **pericardial** arteries are small and are distributed to the pericardium.

(2) The **bronchial** arteries are the nutrient vessels of the lungs, and vary in number, size, and origin. As a rule, there are two left bronchial arteries and one right. The left arise from the thoracic aorta, and the right arises from the first aortic intercostal or from the left bronchial. Each vessel runs along the back part of the corresponding bronchus, dividing and subdividing along the bronchial tubes, supplying them, and the cellular tissue of the lungs.

(3) The **esophageal** arteries are four or five in number, they arise from the front of the aorta and form a chain of anastomoses along the esophagus. They anastomose with branches of the thyroid arteries above, and with ascending branches from the gastric and phrenic arteries below.

(4) The **mediastinal** arteries are numerous small arteries which supply the nodes and areolar tissue in the posterior mediastinum.[3]

The **parietal group** include (1) the intercostal, (2) the subcostal and (3) the superior phrenic.

The **intercostal** arteries are usually nine in number on each side, they arise from the back of the aorta and are distributed to the lower nine intercostal spaces. Each intercostal artery is accom-

[3] See page 309.

panied by a vein and a nerve; and each one gives off numerous branches to the muscles and skin. (See Fig. 141.)

The **subcostal** arteries lie below the last ribs and are the lowest pair of branches derived from the aorta.

The **superior phrenic** arteries are small. They arise from the

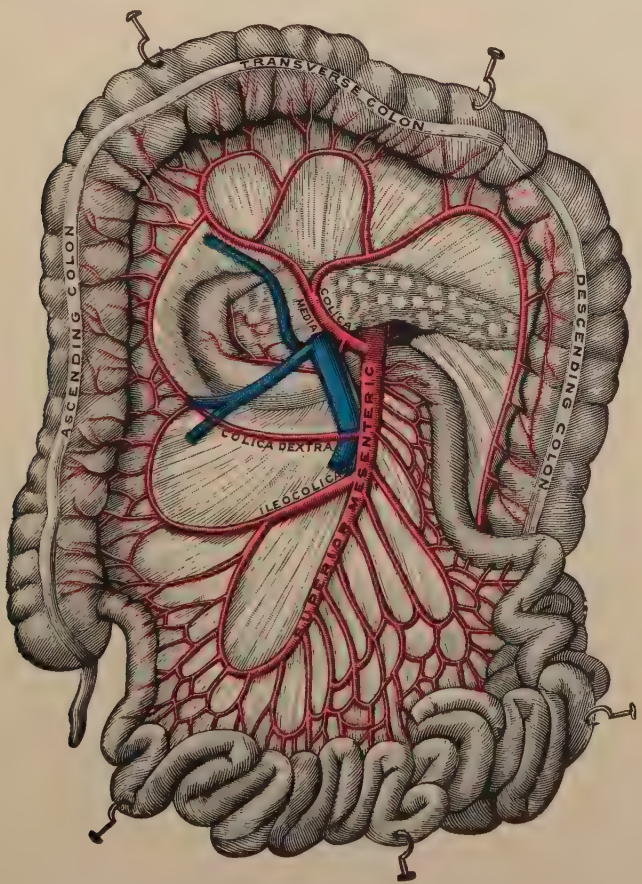


FIG. 146.—SUPERIOR MESENTERIC ARTERY. (Gerrish.)

lower part of the thoracic aorta, and are distributed to the posterior part of the upper surface of the diaphragm.

Branches of the abdominal aorta.—Branches of the abdominal aorta may be divided into three sets, the visceral, the parietal and the terminal.

The **visceral group** includes (1) the celiac; (2) the middle suprarenals; (3) the superior mesenteric; (4) the renal; (5) the

internal spermatic (male) or ovarian (female); and (6) the inferior mesenteric.

(1) The **celiac artery** is a short, wide vessel, usually not more than half an inch (1.25 cm) in length, which arises from the front of the aorta, just below the opening in the diaphragm. It divides into three branches; *viz.*, (*a*) the **left gastric,** which supplies the stomach; (*b*) **the hepatic,** which supplies the liver and sends branches to the stomach, pancreas, gall-bladder and the duodenum; and (*c*) the **splenic** or lineal, which supplies the spleen, and also takes part in the blood supply of the stomach and pancreas. (See Fig. 142.)

(2) The **middle suprarenal arteries** are of small size. They arise from the side of the aorta and pass to the suprarenal or adrenal glands,[4] where they anastomose with branches of the phrenic and renal arteries. (See Fig. 142.)

(3) The **superior mesenteric** artery arises from the fore part of the aorta, a little below the celiac artery. It supplies the small intestine except the duodenum, and also supplies the caecum, the ascending colon and half of the transverse colon. (See Fig. 142.)

(4) The **renal** arteries are of large size, in proportion to the bulk of the organs (kidneys) which they supply. They arise from the sides of the aorta, below the superior mesenteric artery, that of the right side being generally a little lower down than that of the left. Each is directed outward so as to form nearly a right angle with the aorta. (See Fig. 142.)

(5) The **internal spermatic** arteries in the male arise close together from the front of the aorta, a little below the renal arteries. they are distributed to the testes.

The **ovarian** arteries in the female arise from the same portion of the aorta as the spermatic arteries in the male. They supply the ovaries, and, joined to the uterine artery,—a branch of the hypogastric (internal iliac),—also assist in supplying the uterus. During pregnancy the ovarian arteries become considerably enlarged.

(6) The **inferior mesenteric** artery arises from the front of the aorta, about an inch and a half (3.8 cm.) above its bifurcation, and supplies the left half of the transverse colon, and the whole of the descending colon, continued under the name of the superior hemorrhoidal artery, it also takes part in the blood-supply of the rectum. (See Fig. 142.)

The parietal group includes (1) the inferior phrenic arteries;

[4] See page 288.

(2) the first, second, third and fourth pairs of lumbar arteries; and (3) the middle sacral artery.

(1) The **inferior phrenic** arteries arise from the aorta or from the celiac artery and are distributed to the diaphragm. (See Fig. 142.)

(2) The **lumbar** arteries arise from the back part of the aorta

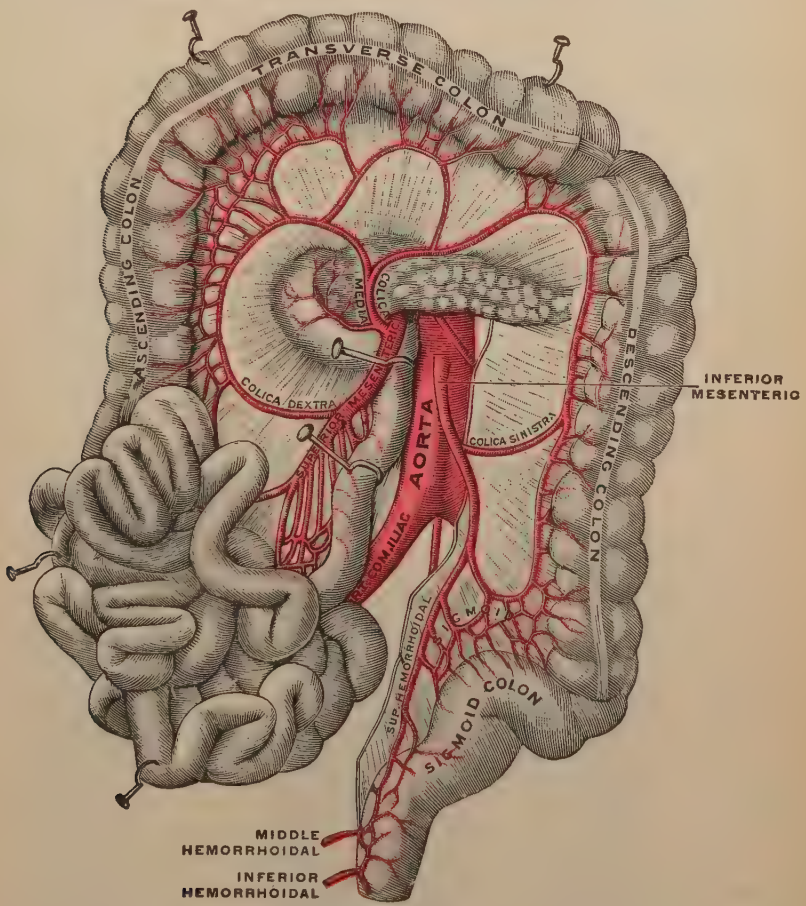


FIG. 147.—INFERIOR MESENTERIC ARTERY. (Gerrish.)

and supply the muscles and walls of the respective regions that their names suggest.

(3) The **middle sacral** artery arises from the back part of the abdominal aorta and passes down in front of the fourth and fifth lumbar vertebra, the sacrum and the cocyx to the cocygeal gland.

The **terminal group** includes the common iliacs which commence at the bifurcation of the aorta (body of the fourth lumbar

vertebra), pass downward and outward about two inches (5 cm.), and then each divides into the hypogastric or internal and the external iliac arteries.

The **hypogastric** or internal iliac artery supplies branches to the pelvic walls, pelvic viscera, the external genitals, and the buttocks. The uterine artery in the female, which supplies the

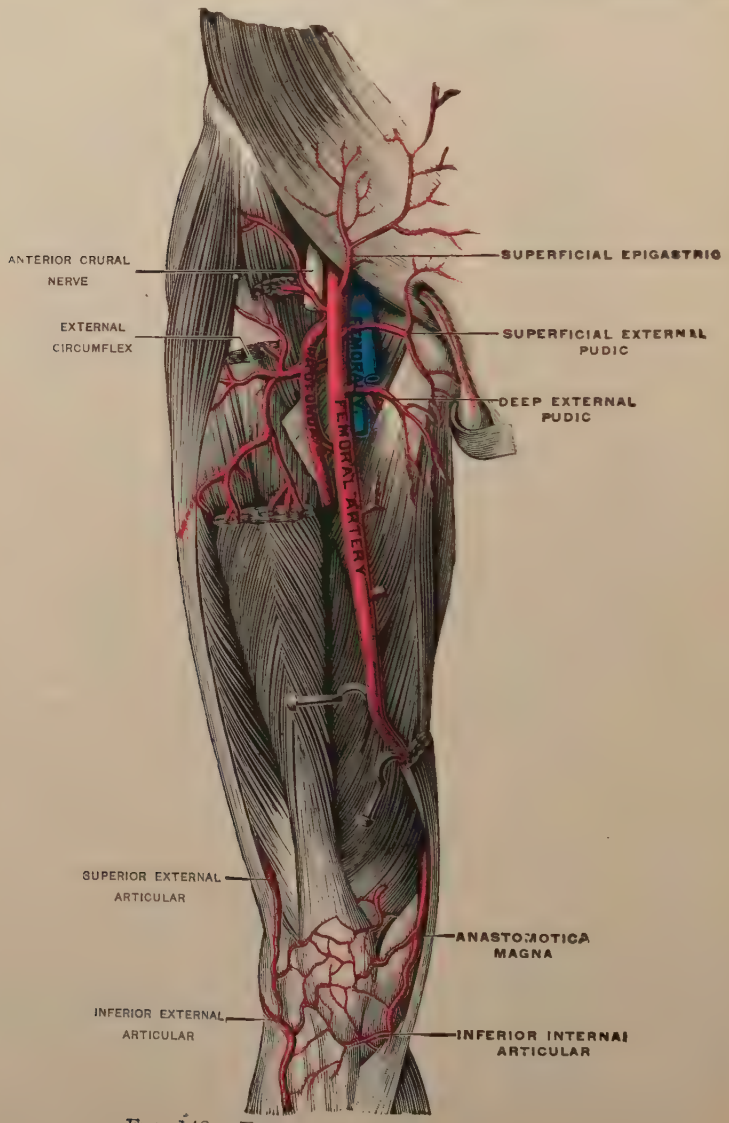


FIG. 148.—FEMORAL ARTERY. (Gerrish.)

tissues of the uterus with blood, is a very important branch of the hypogastric.

The **external iliac** is placed within the abdomen, and extends from the bifurcation of the common iliac to a point half way between the anterior superior spine of the ilium, and the symphysis pubis.

It forms a large, continuous trunk, which extends downward in the lower limb, and is named in successive parts of its course, femoral, popliteal, and posterior tibial.

The **femoral** artery lies in the upper three-fourths of the thigh, its limits being marked above by the inguinal (Poupart's) ligament and below by the opening in the adductor

FIG. 149.—ARTERIES IN THE DORSAL PART OF THE LEG. (Gerrish.)

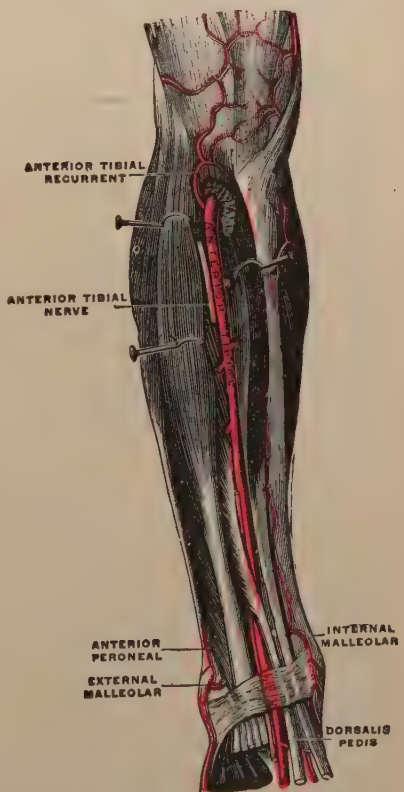


FIG. 150.—ANTERIOR TIBIAL ARTERY. (Gerrish.)

magnus[5] muscle. After passing through this opening the artery receives the name of popliteal. In the first part of its course the artery lies along the middle of the depression on the inner aspect of the thigh, known as the femoral triangle (Scarpa's triangle.[6]) In this situation the beating of the artery may be felt, and the circulation through the vessel may be most easily controlled by pressure.

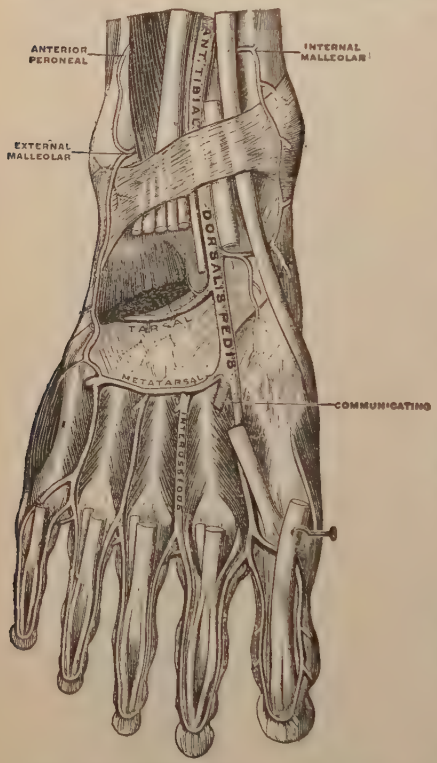


FIG. 151.—ARTERIES OF THE DORSUM OF THE FOOT. Of the dorsal interosseous only the second is labelled. (Gerrish.)

The **popliteal** artery, continuous with the femoral, is placed at the back of the knee; just below the knee joint it divides into the posterior tibial and anterior tibial arteries.

The **posterior tibial** artery lies along the back of the leg, and extends from the bifurcation of the popliteal to the ankle, where it divides into the **medial** and **lateral plantar** arteries.

The **peroneal** artery is a large branch given off by the posterior tibial just about an inch (2.5 cm.) below the bifurcation of the popliteal.

The **anterior tibial** artery, the smaller of the two divisions of the popliteal trunk, extends along the front of the leg to the bend of the ankle, whence it is prolonged into the foot under the name of the **dorsalis pedis** artery. This unites with the medial and lateral plantar arteries to form the **plantar arch** which supplies blood to the foot.[7]

[5] See page 102.

[6] Femoral triangle (Scarpa's triangle) is a name given to a triangular space situated on the upper, anterior, and inner surface of the thigh. It is bounded above by Poupart's ligament, on the outer side by the sartorius muscle, and on the inner side by the adductor.

[7] Drawing the outline of the aorta with its branches as an arterial tree and labeling the arteries will greatly aid the student in mastering the arterial distribution.

VEINS

The arteries begin as large trunks, which gradually become smaller and smaller until they end in arterioles, which merge into capillaries, while the veins begin as small branches called venules which at first are scarcely distinguishable from the capillaries, and unite to form larger and larger vessels. They differ from the arteries in their larger size, greater number, thinner walls, and in the presence of valves which prevent backward circulation. The capacity of the venous system is greater than that of the arterial. The veins may be divided into three sets—superficial, deep and venous sinuses.

The **superficial veins** are found immediately beneath the skin.

The **deep veins** accompany the arteries and are usually called by the same names.

The **venous sinuses** are found only in the interior of the skull. They are formed by a separation of the layers of the dura mater, the fibrous membrane which covers the brain. Their outer wall consists of the dura mater, and their inner lining of endothelium is continuous with the lining membrane of the vessels that communicate with them. (See Fig. 107.)

The superficial and the deep veins have very frequent communications with each other, and the anastomoses of veins are always more numerous than those of arteries. The deep veins accompanying the smaller arteries, such as the brachial, ulnar radial, peroneal and tibial are found in pairs, one on each side of the vessel and are called venæ comitantes or companion veins. Usually the larger arteries, such as the femoral, popliteal, axillary and subclavion have only one accompanying vein (vena comes).

The **systemic veins.**—The systemic veins are divided into three groups:—(1) veins that empty into the heart, (2) veins that empty into the superior vena cava and (3) veins that empty into the inferior vena cava.

(1) Most of the veins of the heart empty into the right auricle, some directly and some by way of the coronary sinus, a wide venous channel which ends in the right auricle. A few of the smallest cardiac veins end in the ventricles.

(2) The veins of the head, neck, upper extremities, and the walls of the thorax empty into the **superior vena cava** which carries the blood to the heart.

(3) The veins of the lower limbs, the lower part of the trunk, and the abdominal viscera, empty into the inferior **vena cava,** which carries blood to the heart.

Veins of the head and neck.—The blood returning from the head and neck flows on each side into two principal veins, the external and internal jugular.

External jugular veins.—The right and left external jugular veins are formed in the substance of the parotid glands by the union of two of the veins of the face. This union takes place on a

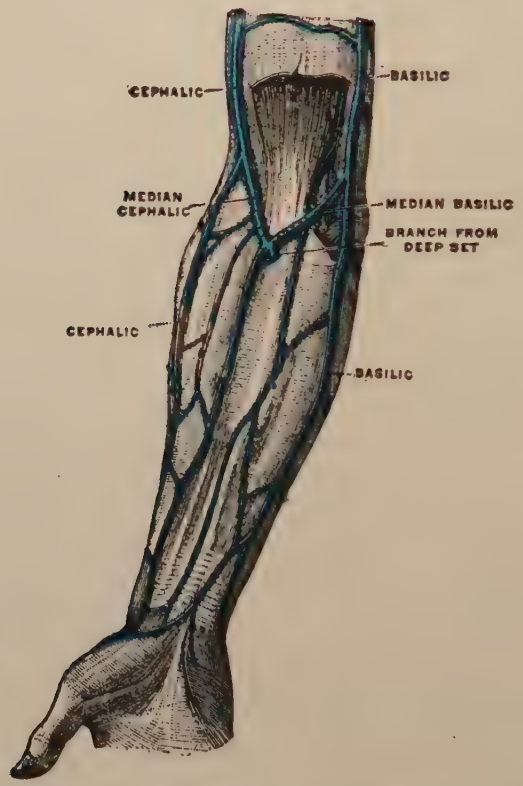


Fig. 152.—Superficial Veins of Front of Forearm and Lower Part of Arm. (Gerrish.)

level with the angle of the mandible and each vein descends almost vertically down the neck to its termination in the subclavian. These two veins receive the blood from the deep parts of the face and the exterior of the cranium.

Internal jugular veins.—These veins begin at the base of the skull and descend on either side of the neck, first with the external

carotid, then with the common carotid, and join at a right angle with the subclavian to form the innominate (brachiocephalic) vein. They receive the blood from the veins and sinuses of the cranial cavity, the superficial parts of the face, and from the neck. (See Fig. 154.)

Veins of the upper extremities.—The blood from the upper limbs is returned by a deep and a superficial set of veins. The deep veins are the venæ comitantes of the forearm and arm and are called by the same names as the arteries. They communicate

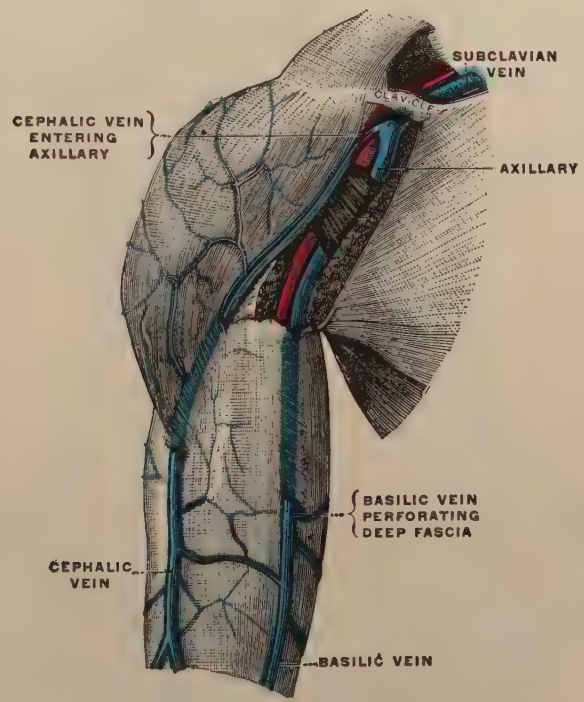


FIG. 153.—SUPERFICIAL VEINS OF FRONT OF ARM AND SHOULDER. (Gerrish.)

with the superficial veins at the hand and elbow, and the vena comes of the brachial artery unites with a superficial vein, *i.e.*, the basilic, to form the axillary vein.

The superficial veins.—The superficial veins are much larger than the deep, and take a greater share in returning the blood, especially from the distal portion of the limb. They commence in two plexuses, one on the back of the hand and one on the front of the wrist. They comprise the following:—

The **cephalic** vein begins in the dorsal plexus and ascends

the radial side of the forearm to a little above the bend of the elbow, where it joins the median cephalic vein to form the cephalic of the upper arm.

The **basilic vein** begins in the dorsal plexus and extends upward along the posterior part of the ulnar side of the forearm to a little above the bend of the elbow, where it joins the median basilic to form the basilic of the upper arm.

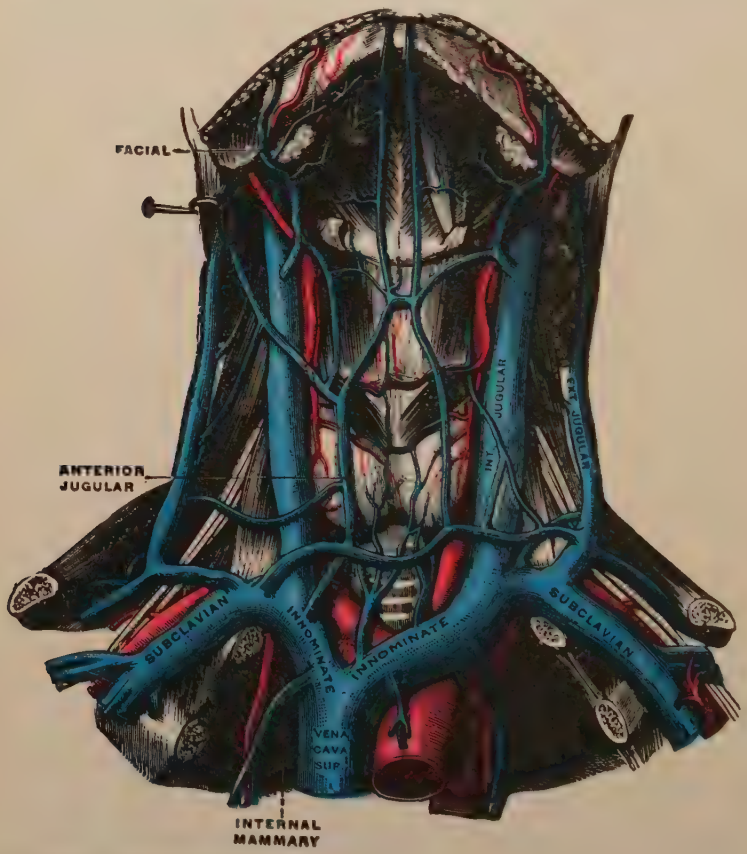


FIG. 154.—VEINS OF THE NECK AND UPPER PART OF THORAX. Front View. (Gerrish.)

The **axillary vein.**—The axillary vein is a continuation of the basilic in the upper arm. It ends at the outer border of the first rib, in the subclavian vein. This vein accompanies the axillary artery and also receives blood from the cephalic and other veins of the upper extremity.

The subclavian vein.—This vein is a continuation of the

axillary extending from the first rib to the joint between the sternum and clavicle, where it unites with the internal jugular to form the innominate vein.

The innominate veins.—The innominate (brachiocephalic) veins formed by the union of the subclavian and internal jugular on each side transmit the blood returning from the head and neck, the upper limbs, and a part of the thoracic wall; they end below by uniting to form the superior vena cava. Both innominate veins are joined by many side tributaries; they also receive, at the junction of the subclavian and internal jugular, the lymph,[8] on the left side from the thoracic duct, and on the right from the right lymphatic duct.

The superior vena cava.—The superior, or descending, vena cava, is formed by the union of the right and left innominate veins, just behind the junction of the first right costal cartilage with the sternum. It is about three inches (7.5 cm.) long, and opens into the right auricle, opposite the third rib.

Thoracic veins.—The great majority of the thoracic veins follow the same course as the arteries, and bear the same names.

Two exceptions are the inferior vena cava and the azygos veins.

Veins of the lower extremities.—The blood from the lower limbs is also returned by a superficial and a deep set of veins. They are more abundantly supplied with valves than the veins of the upper limbs.

The superficial veins.—The superficial veins of the lower extremity are the great or internal saphenous, and the small or external saphenous. They receive many tributaries.

The **great saphenous**, the longest vein in the body, extends from the ankle to within an inch and one-fifth (3 cm.) of the inguinal ligament. It lies along the inner side of the leg and thigh and terminates in the femoral vein.

The **small saphenous** arises from the sole of the foot, and, passing up the back of the leg, ends in the deep popliteal.

The deep veins.—Below the knee the deep veins accompany the arteries in pairs, as venæ comitantes, and as in the upper limbs are called by the same names. The veins from the foot empty into *anterior tibial* and *posterior tibial veins*. They unite to form the single *popliteal* vein, which is continued as the *femoral* and becomes the *external iliac*.

The femoral veins.—These vessels are a continuation of the popliteal veins and extend from the opening in the adductor magnus to the level of the inguinal ligament.

[8] See pages 269 and 270.

The external iliacs.—These vessels are a continuation of the femoral veins, and extend from the level of the inguinal (Poupart's) ligament, on either side, to the joint between the sacrum and the ilium. They receive the blood from the deep and superficial veins of the lower limbs. (See Fig. 142.)

The hypogastric veins.—They are formed by the union of veins corresponding to the branches of the hypogastric arteries.

FIG. 155.—SUPERFICIAL VEINS OF THE FRONT OF THE LEG AND FOOT. (Gerrish.)

FIG. 156.—SUPERFICIAL VEINS OF THE FRONT OF THE RIGHT THIGH. (Gerrish.)

They accompany the hypogastric arteries and unite with the external iliac veins to form the common iliacs. (See Fig. 142.)

The common iliacs.—The common iliacs extend from the base of the sacrum to the fifth lumbar vertebra, and then the two common iliacs unite to form the inferior vena cava. (See Fig. 142.)

The inferior vena cava.—The inferior, or ascending vena cava, returns the blood from the lower limbs, pelvis, and abdomen.

It begins at the junction of the two common iliacs, and thence ascends along the right side of the aorta, perforates the diaphragm and terminates by entering the right auricle of the heart. The inferior vena cava receives many tributaries, the chief of which are the lumbar, ovarian, renal, and hepatic veins. (See Fig. 142.)

Supplementary channel.—A supplementary channel between the inferior and superior vena cava is formed by the azygos veins. They are three in number and lie on the sides of the front of the vertebral bodies.

The **right** or **major azygos** vein is an upward continuation of the lumbar vein which communicates with the common iliac vein, and often with the inferior vena cava and renal vein. It ascends on the right side of the vertebral column to the level of the fourth thoracic vertebra, where it empties into the superior vena cava. It receives the right subcostal and intercostal veins, the hemiazygos veins, several esophageal, mediastinal and pericardial veins, and near its termination the right bronchial vein. The intercostal veins on the left side below the upper three intercostal spaces usually form two trunks named the hemiazygos (left lower or minor azygos) and the accessory hemiazygos veins (left upper azygos).

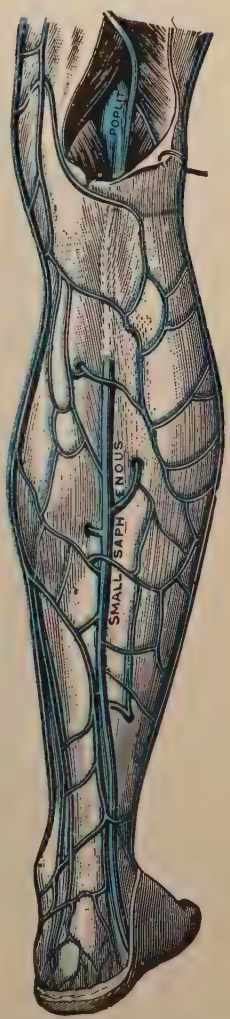


FIG. 157.—SUPERFICIAL VEINS OF THE DORSUM OF THE LEG. (Gerrish.)

The **hemiazygos** (left lower or minor azygos) vein commences

in the left lumbar or renal vein. It ascends on the left side of the vertebral column, and at about the level of the ninth thoracic vertebra it connects with the right azygos vein. It receives the

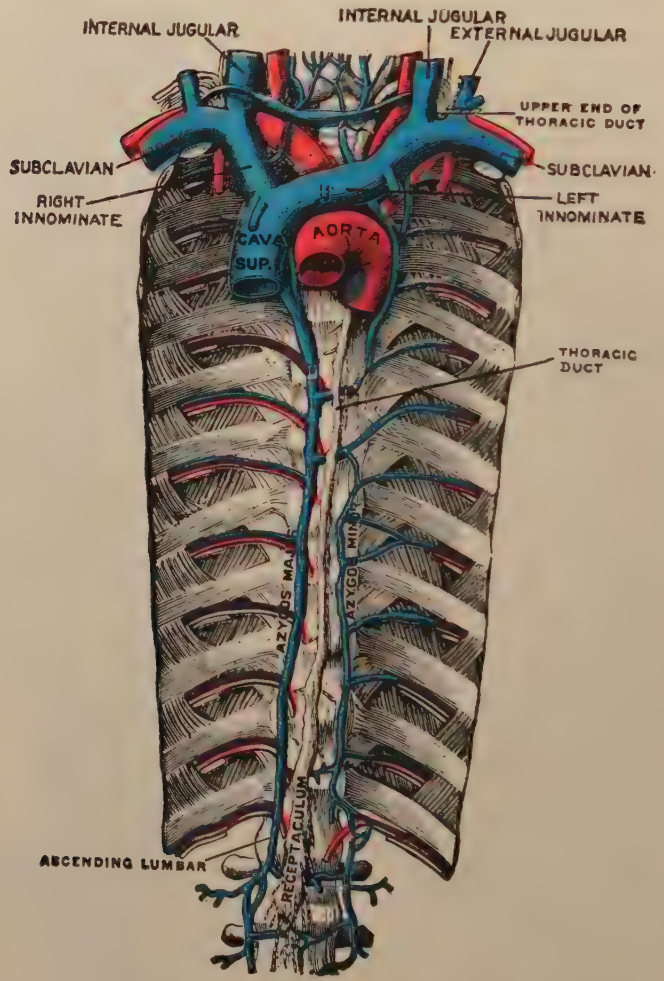


FIG. 158.—AZYGOS AND INTERCOSTAL VEINS, ALSO THORACIC DUCT. (Gerrish.)

lower four or five intercostal veins of the left side and some esophageal and mediastinal veins.

The **accessory hemiazygos** (left upper azygos) vein connects above with the superior intercostal vein, and opens below into

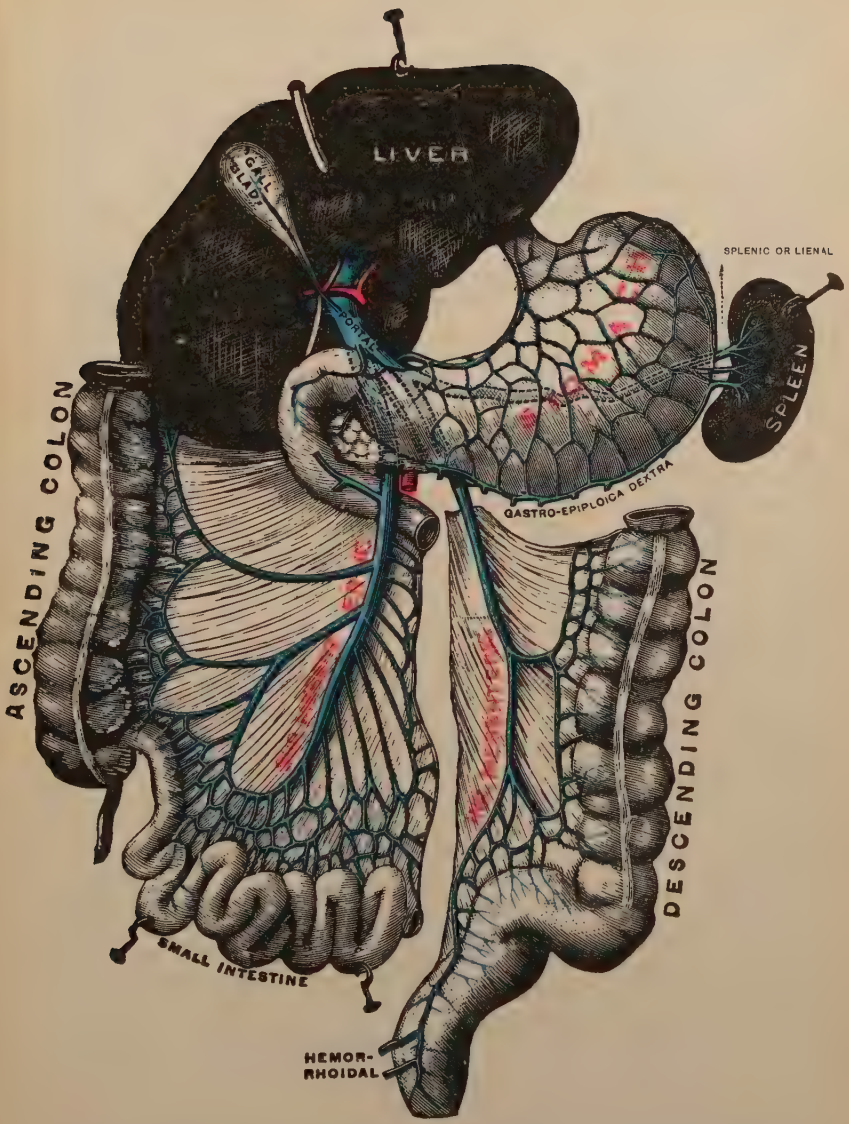


FIG. 159.—PORTAL SYSTEM OF VEINS. The liver is turned upward and backward, and the transverse colon and most of the small intestines are removed. (Gerrish.)

either the hemiazygos, or the major azygos vein. It varies considerably in size, position and arrangement. It receives veins from the three or four intercostal spaces between the highest left intercostal vein and highest tributary of the hemiazygos; the left bronchial vein sometimes opens into it.

The bronchial veins.—The bronchial veins return the blood from the larger bronchi, and from the structures at the roots of the lungs; that of the right side opens into the azygos vein, near its termination; that of the left side, into the highest left intercostal or the accessory hemiazygos vein. A considerable quantity of the blood which is carried to the lungs through the bronchial arteries is returned to the left side of the heart through the pulmonary veins.

It is important to remember that in case of obstruction in the inferior vena cava the azygos veins form a supplementary channel by which blood can be conveyed from the lower part of the body to the heart.

The accessory or portal system.—All the veins which bring back the blood from the abdominal part of the intestinal tract (except the lower part of the rectum) and from the spleen, pancreas and gall bladder are included in the portal system. Just back of the pancreas, the splenic, the inferior and superior mesenteric unite to form the portal tube. The portal tube passes upward and to the right for about three inches (7.5 cm.), then enters the liver, where it divides like an artery into capillary-like vessels termed sinusoids. These capillaries unite with another set of capillaries which arise from the hepatic artery, and form the hepatic vein, which carries the blood from the liver to the inferior vena cava. Thus it will be seen that the liver receives blood from two sources—(1) the portal tube which carries blood to the liver in order that certain chemical changes may take place, and (2) the hepatic artery which carries blood to the liver for nutritive purposes. The blood from both sources of supply is carried from the liver by the hepatic vein.

The portal tube and all its branches constitute the portal system, described as a third or accessory system.

SUMMARY

- **Arteries**
  - Begin as large trunks, grow smaller.
  - Usually deep seated for protection.
  - Division
    - Two branches of nearly equal size.
    - Trunk gives off several branches.
    - One branch that divides into several.
  - Anastomosis or inosculation—distal ends unite.
  - Plexus—many inosculations within limited area.
  - Usually straight (facial and uterine are tortuous).

- **Divisions of the Vascular System**
  - **Pulmonary System**
    - Provides for pulmonary circulation.
    - 1. Pulmonary artery
      - Right pulmonary artery—right lung.
      - Left pulmonary artery — left lung.
    - 2. Capillaries connect arterioles and venules.
    - 3. Four pulmonary veins—two from each lung.
  - **General System**
    - Provides for systemic circulation.
    - 1. Aorta and all its branches.
    - 2. Capillaries connect arterioles and venules.
    - 3. Veins empty into heart either directly or by means of inferior and superior vena cava.

- **Aorta**
  - **Ascending Aorta**
    - Right and left coronary—supply the heart.
  - **I. Arch of Aorta**
    - Innominate
      - Right common carotid
        - Int. carotid — brain, eye, forehead and nose.
        - Ext. carotid—throat, tongue, face, ears, walls of cranium.
      - Right subclavian, — axillary, brachial
        - Ulnar
          - Superficial and deep volar arch.
        - Radial—Deep volar arch.
    - Left common carotid—same branches as right common carotid.
    - Left subclavian—same branches as right subclavian.
  - **II. Thoracic Aorta**
    - Visceral Group
      - Pericardial—to the pericardium.
      - Bronchial—to the lung tissue.
      - Esophageal—to the esophagus.
      - Mediastinal—to the nodes and areolar tissue in the mediastinum.
    - Parietal Group
      - Intercostal—lower nine intercostal spaces.
      - Subcostal—below the last ribs.
      - Superior phrenic—posterior part of upper surface of diaphragm.
    - Diaphragm muscle is dividing line between thoracic and abdominal aorta.
  - **III. Abdominal Aorta**
    - Visceral Group
      - Celiac artery
        - Gastric—stomach.
        - Hepatic—liver, stomach, pancreas, gall bladder and duodenum.
        - Splenic or lienal—spleen, stomach, and pancreas.
      - Middle suprarenal—suprarenal bodies.
      - Sup. mesenteric
        - Small intestine, except duodenum, also cæcum, ascending colon and half of transverse colon.

- **Aorta**
  - **III. Abdominal Aorta**
    - **Visceral Group**
      - Renal—kidneys.
      - Internal spermatic—testes.
      - Ovarian—ovaries and uterus.
      - Inf. mesenteric — Left half of transverse colon, and descending colon.
    - **Parietal Group**
      - Inferior phrenic—diaphragm.
      - Lumbar—dorsal, spinal, and abdominal walls.
      - Middle sacral—sacrum, coccyx, and coccygeal gland.
    - **Terminal Group**—Common iliacs.

- **Common Iliac Arteries**
  - Hypogastric—walls and viscera of pelvis.
  - External iliac—femoral, popliteal
    - Posterior tibial → Lateral plantar, Medial plantar, Peroneal. → Plantar arch.
    - Anterior tibial → Dorsalis pedis. → Plantar arch.

- **Veins**
  - Begin small, grow larger.
  - **Differ from arteries**
    - Larger size.
    - Greater number.
    - Thinner walls.
    - Valves.
    - More frequent anastomosis.
  - **Sets**
    - Superficial.
    - Deep
      - **Venæ Comitantes**: Brachial. Ulnar. Radial. Peroneal. Tibial.
      - **Vena Comes**: Femoral. Popliteal. Axillary. Subclavian.

Veins of Heart—Empty into right auricle, and few into right ventricle.

Superior Vena Cava Group

- **External Jugular Veins**
  - Receive blood from deep parts of the face and the exterior of the cranium.
  - Formed in parotid gland, terminate in the subclavian.
- **Internal Jugular Veins**
  - Receive blood from the veins and sinuses of the cranial cavity, superficial parts of face and neck.
  - Begin at base of skull, unite with subclavian.
- **Axillary Veins**
  - (1) Receive blood from the deep veins of the forearm and arm.
  - They accompany the arteries and are called by the same names.
  - (2) Receive blood from superficial veins — Basilic. Cephalic.
  - Continuation of the basilic in upper arm.
- **Subclavian Veins**
  - Continuation of axillary from first rib to the joint between the sternum and clavicle.
  - Unite with internal jugular to form innominate.
- **Innominate Veins**
  - Transmit blood from head, neck, upper limbs, and part of thoracic wall. Receive lymph.
  - Formed by union of internal jugular and subclavian.
  - One on each side of body.
- **Superior Vena Cava**
  - Formed by union of right and left innominate veins. Three inches long.
  - Opens into right auricle.

Thoracic Veins—Majority follow same course and bear same name as arteries.

Inferior Vena Cava Group

- **Femoral Veins**
  - Continuation of the popliteal and extend from opening in adductor magnus muscle to the inguinal ligament.
  - (1) Receive blood from the superficial veins, two are important: Great saphenous; Small saphenous.
  - (2) Receive blood from deep veins of foot, leg, and thigh. They accompany the arteries and are called by the same names.
- **External Iliacs**—Continuation of femoral veins. Extend from inguinal ligament to the joint between sacrum and ilium.
- **Hypogastrics**—Formed by union of veins corresponding to branches of internal iliac artery.
- **Common Iliacs**—Formed by union of external iliacs and hypogastrics. Extend from base of sacrum to the fifth lumbar vertebra.
- **Inferior Vena Cava**
  - Formed by union of the common iliacs.
  - Extends from fifth lumbar vertebra to the right auricle of the heart.
  - Receives many tributaries corresponding to arteries given off from the aorta.

Supplementary Channel

1. Right azygos vein
2. Hemiazygos vein
3. Accessory hemiazygos vein

Connect with superior vena cava above, and inferior vena cava below.

Portal Circulation

- **Portal Tube**
  - Splenic, inferior and superior mesenteric veins — Unite to form portal tube.
  - Carries blood to liver, breaks up into capillary-like vessels termed sinusoids. then unites with capillaries from hepatic artery to form hepatic vein.
- **Hepatic Vein**—empties into inferior vena cava.

CHAPTER XIII

THE BLOOD VASCULAR SYSTEM CONTINUED: THE GENERAL CIRCULATION; BLOOD-PRESSURE; FETAL CIRCULATION

The blood is contained in a closed set of tubes which it completely fills. Interposed in this set of tubes is the heart which fills with blood from the veins and then contracts, thereby forcing a part of this blood into the lungs and a part to all the rest of the body.

To trace the general circulation, we will begin with the venous blood which is returned to the right auricle by the superior and inferior vena cava. It enters and fills the right auricle and the right ventricle, which for the time being may be thought of as a single chamber with the tricuspid valve open.[1] Then the auricle contracts and forces the blood over the open valve into the ventricle, which has already been passively filled, and now becomes well distended by the extra supply. The blood gets behind the cusps of the tricuspid valve and closes them. After a brief pause, (possibly $^1/_{10}$ of a second) the ventricle contracts and forces the blood over the open semilunar valves into the pulmonary artery. The pulmonary artery divides into two branches and carries the blood to the lungs, where it passes through the innumerable capillaries that surround the alveoli or air sacs of the lungs. These capillaries unite to form veins, and these unite to form larger veins, until finally two pulmonary veins return the blood from each lung to the left auricle and ventricle. The left auricle now contracts and forces the blood over the open bicuspid valve into the left ventricle, just as described for the right side of the heart. The bicuspid valve is closed in the same way as the tricuspid and after a brief pause the left ventricle contracts, forcing the blood over the open semilunar valve, into the aorta. From the aorta and its branches the blood travels in the capillaries to every part of the body. The capillaries unite to form veins, and finally the blood is returned by means of the venæ cavæ to the right auricle, which completes the circuit. This description of the general circulation is accurate but the student must understand that both sides of the heart contract almost simultaneously, *i.e.*, the blood fills the auricles and ventricles on both sides of the heart at the

[1] It is a mistake to think that the blood all accumulates in the auricle before any is forwarded to the ventricle.

same time, both auricles contract practically together,[2] forcing the blood over the open valves into the ventricles, moreover the ventricles pump out equal quantities of blood, but the blood from the left ventricle is sent on a longer journey than the blood from

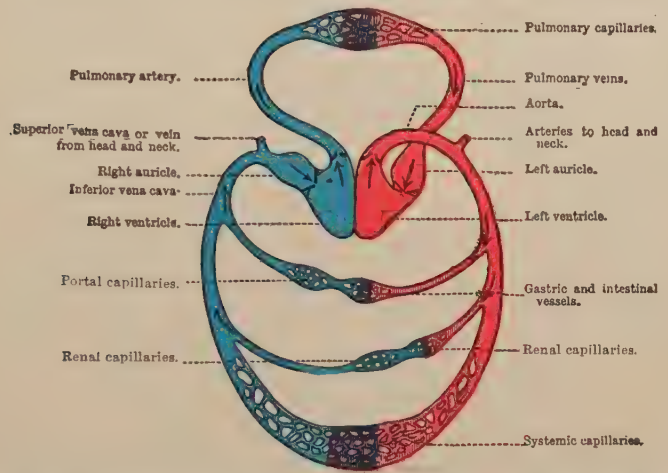


FIG. 160.—DIAGRAM OF THE CIRCULATION. Right and left side are reversed as though the observer were looking at another subject. The pulmonary circulation is from the right ventricle to the left auricle. The systemic circulation is from the left ventricle to the right auricle. (Halliburton.)

the right. After a brief pause both ventricles contract, and the blood is forced into the pulmonary artery, and into the aorta.

The pulmonary circulation.—The lesser circulation, from the right ventricle to the left auricle, is called the pulmonary circulation. The purpose of the pulmonary circulation is to carry the blood which has been through the system, giving up oxygen and collecting carbon dioxide, to the air sacs of the lungs, where the red cells are recharged with oxygen, and the carbon dioxide is reduced to the standard amount.[3]

The systemic circulation.—The more extensive circulation, from the left ventricle to all parts of the body, and the return to the right auricle, is known as the systemic circulation. The purpose of the systemic circulation is to carry oxygen and nutritive material to all parts of the body, and gather up waste products. After leaving the left ventricle, portions of the blood pursue different courses, some enter the coronary arteries, some go to the head, some to the upper and lower extremities, and some to the

[2] Careful measurements have shown that the contraction of the left auricle lags behind that of the right auricle from 0.01 to 0.03 of a second.

[3] See page 315.

different internal organs. Some portions go on shorter journeys and arrive back at the heart sooner than other portions that travel farther away from the center. In man it is thought to require about 23 seconds[4] to complete a circuit of medium length from the left ventricle to the right auricle (systemic circulation). The blood which enters the right auricle has to go through the lungs (pulmonary circulation) before it gets back to the left auricle. This double circulation, pulmonary and systemic, is constantly going on, as each half of the heart is in a literal sense a force pump.

The heart as a pump.—The muscles[5] of the auricles and ventricles are so arranged that when they contract, they lessen the capacity of the chambers which they enclose. When this happens the blood from the contracting chamber is expelled in the direction of the arrows, (See Fig. 160) since the valves prevent its passage in the opposite direction.

The first visible sign of contraction is noted where the veins empty into the auricles. The sinu-auricular node around the opening of the superior vena cava into the right auricle is the causal factor. It is therefore sometimes called the pace-maker of the heart. From this spot the wave of contraction spreads over the muscles of both auricles. These contract simultaneously, driving the blood into the ventricles. The wave of contraction now spreads over the ventricles, causing them to contract simultaneously driving the blood into the arteries.

The wave of contraction.—If a stimulus be applied to one end of a muscle, a wave of contraction sweeps on over the entire tissue. It is therefore easy to conceive how a wave of contraction can sweep over the muscular tissue of the auricles which is practically continuous. The question is—how is this wave transmitted to the muscular tissue of the ventricles which is *not* continuous with that of the auricles? The connecting pathway is furnished by a peculiar band of cardiac or modified muscle known as the auriculoventricular bundle of His which transmits the nerve impulses and causes the wave of contraction to spread over the ventricles.[6]

Heart-block and fibrillation.—Experimentally the bundle of His may be damaged, with the result that it loses its power to conduct nerve impulses from the auricles to the ventricles. The

[4] This shows how rapidly substances introduced into the blood-stream can make their way over the body.

[5] See page 201 and Fig. 126.

[6] See page 207.

auricles will continue to contract at the rate established by the nerve impulses but the ventricles adopt a slower rate, depending entirely on the power of contraction inherent in cardiac tissue. This condition is known as heart-block, and in human beings is caused by disease, or by over-doses of drugs, such as digitalis, that lessen the conductivity of the bundle of His. Pathological changes in the bundle of His may interfere with the passage of nerve impulses to one or all of the auricles and ventricles. Under such conditions cardiac muscle does not respond with strong unified contractions but various strands of muscle contract independently of others. This condition is known as fibrillation and if extreme or long continued, the heart is unable to carry on its work.

The heart beat.—By a heart beat we mean a coördinated contraction of the cardiac muscle resulting in the expulsion of blood from both ventricles. It consists of (1) a period of contraction called the *systole*, (2) a period of dilatation called the *diastole*, and (3) a period of rest. These three phases constitute a *cardiac cycle* and correspond to the heart beat. The heart of a man at rest may beat seventy-two times a minute. Some individuals have a lower and others a higher average.[7] If we assume that the heart beats 75 times a minute, the time required for a cardiac cycle is about 0.8 of a second, and half of this, or 0.4 of a second, represents the quiescent phase. When the heart beats more rapidly it is the rest period that is shortened.

Heart sounds and murmurs.—If the ear be applied over the heart, certain sounds are heard, which recur with great regularity. Two chief sounds can be heard during each cardiac cycle. The first sound is a comparatively long, booming sound; the second, a short, sharp, sudden one. The sounds resemble the syllables *lubb dup*. The first sound is thought to be due to vibrations caused by the closure of the auriculoventricular valves, the second is attributed to vibrations set up by the sudden closure of semilunar valves.[8] In certain diseases of the heart these sounds become changed and obscure, and are called murmurs. These are often due to failure of the valves to close properly, thus allowing regurgitation of the blood.

Cause of the heart beat.—The cause of the heart-beat is still an unsettled question. Two points of view persist, one, the *neurogenic theory* makes the contained nerve cells responsible for

[7] See page 249.

[8] Observers have described three sounds, the third a soft low sound at the beginning of the ventricular diastole. Other sounds have also been described.

the rhythmic contractions, and the other, the *myogenic theory*, makes the automaticity of the heart muscle responsible. General belief favors the theory that the function of the nerve tissue is regulatory, that the contractions are due to the inherent power of automaticity, and that the stimulus which excites the contractions is a chemical one dependent upon the presence of definite proportions of inorganic salts in the blood. Four are especially important, namely: sodium, calcium, potassium and magnesium. Under normal conditions these salts are always present, and as the blood is constantly passing through the heart, it follows that the heart is subjected to a continual stimulus. It is natural to question why the heart is not in a state of continuous contraction. In other words how is relaxation possible? In answer it may be stated that there is a well-marked antagonism between the effects of calcium, and the effects of sodium and potassium. Calcium promotes a state of contraction, sodium and potassium promote a state of relaxation. It is possible therefore that the contraction and relaxation characteristic of heart muscle are brought about by interactions of these salts and the muscles of the heart.

Automaticity.—The most remarkable power of cardiac muscle is its automaticity. By this we mean that the stimuli which excite it to activity arise within the tissue itself. Skeletal muscle rarely contracts except in response to the arrival of stimuli by way of the motor nerves. Visceral muscle shows an automatic tendency, but this power is most highly developed in the heart. This may be demonstrated by removing the heart of a frog from the body of the animal. The heart will continue to beat for hours provided it is kept moist with Ringer's solution.[9] The degree of automatic power possessed by different regions of the heart varies. Some parts beat faster than others. The most rapidly contracting part is the sinu-auricular node of the right auricle. It is from this particular spot that the wave of contraction radiates, and from here it is transmitted over the bundle of His to the ventricles. Thus the normal sequence of the contraction depends

[9] The exact composition of Ringer's solution has been varied by different workers, but the formula is usually given as:

Sodium Chlorid	0.9	per cent
Calcium Chlorid	0.024	" "
Potassium Chlorid	0.042	" "

Locke's solution is frequently used instead of Ringer's. The formula is the same, but the following are added.

Sodium Bicarb.	0.01 to 0.03 per cent
Dextrose	0.01 per cent

upon the fact that the automaticity of the right auricle is more highly developed than that of the ventricles.

Nervous control of the heart.—Although the heart contracts automatically and rhythmically, it is under normal conditions controlled by two sets of nerves. These consist of inhibitory nerves coming to the heart from the vagus or pneumogastric nerve and accelerator nerves from the sympathetic system. The inhibitory nerves have their cell bodies situated in the medulla where they form a cardio-inhibitory center. It is assumed that the cardio-accelerator center is also located in the medulla, but the location of this center has not been made out satisfactorily. The way in which these nerves regulate the heart's action is not known, but it is generally believed that both the inhibitory and accelerator nerves are in a state of constant, though slight, activity. This means that the heart beat is controlled by two antagonistic influences, one tending to slow the heart action, and the other to quicken it. If the inhibitory center is stimulated to greater activity, the heart is slowed still further. If this center is inhibited, the heart rate is increased, because the inhibitory action is removed. Stimulation of the accelerator nerves results in a quickened heart beat, and section of these nerves slows the heart.

Factors affecting the frequency and strength of the heart's action.—The frequency and strength of the heart's action are affected by (1) the temperature of the blood; (2) such characteristics of heart muscle as tone, irritability, contractility, conductivity, and (3) physical factors such as size, sex, age, posture and muscular exercise; (4) changes in the condition of the blood-vessels, (5) disposition, and (6) certain internal secretions

By experimenting on animals it has been possible to demonstrate that abnormally high or low temperatures of the blood affect the frequency of the heart beat. If the heart is perfused with hot liquid the rate is increased in proportion to the temperature until the maximum point, about 111° F. (44° C.[10]) is reached. If the temperature is raised above this the heart soon ceases to

[10] The freezing point of Centrigrade is 0.
The freezing point of Fahrenheit is 32°.
The boiling point of Centigrade is 100°.
The boiling point of Fahrenheit is 212°.

To change Fahrenheit to Centigrade we subtract 32° and multiply by $\frac{5}{9}$.

To change Centrigrade to Fahrenheit we multiply by $\frac{9}{5}$ and add 32°.

beat. In fever the increased rate of the heart action is thought to be partly due to the effect of the higher temperature of the blood on the heart muscle. On the other hand, if cold liquid is perfused through an animal heart, the rate is decreased, and it ceases to beat at about 62° F. (17° C.).

Conditions that affect the *irritability*, *contractility*, and *conductivity* of the heart muscle, or reduce its normal *tone*, are likely to change the frequency of the heart beat, either accelerating or slowing the action. If the tone is below par, the strength of the contractions is diminished. The contraction of any kind of muscular tissue is dependent upon the power of conductivity, but cardiac muscle is specially dependent on this power, because the nerve fibers are *not* widely distributed through its substance.

In almost all cases of warm-blooded animals the frequency of the heart beat is in inverse proportion to the *size* of the body, *i.e.*, the larger the body the slower the heart beat, and *vice versa*. An elephant's heart beats about 25 times per minute, a mouse's heart about 175 times per minute. The frequency of the heart beat is somewhat more rapid in women than in men. Before birth the heart beats of a female fetus are generally 140 to 145 per minute, and that of the male 130 to 135. It is on this difference that attempts to foretell the sex are based.

Age has a marked influence. At birth the rate is about 140 per minute; at three years about 100; in youth about 90; in adult life about 75; in old age about 70; and in extreme old age 75 to 80.

The *posture* of the body influences the rate of the heart beat. The rate is higher when an individual is erect than when he is recumbent. Typical figures would be standing 80; sitting 70; and recumbent 66.

If an individual remains in a recumbent position and keeps quiet the work of the heart may be decreased considerably. This is the reason why certain types of heart cases are kept in a recumbent position.

It is a well-known fact that muscular *exercise* increases the frequency of the heart beat. This insures an increased flow of blood and hence increased quantities of food and oxygen as well as more rapid removal of wastes. It is due to (1) the activity of the cardiac centers[11] in the medulla being affected by the motor impulses from the brain to the muscles. Various experiments indicate that the cardio-inhibitory center is depressed and consequently the rate of the heart is increased. (2) In continuous

[11] See page 154.

muscular activity the reaction of the blood tends to become more acid. This excites the respiratory center,[12] and also the cardio-inhibitory center, thus increasing the respirations and the heart beat. (3) The pressure of the contracting muscles on the veins sends more blood to the heart, so that the right side is filled more rapidly. This increased pressure of the blood against the walls of the heart reflexly accelerates the heart beat.

In order to function properly the heart requires a certain amount of resistance, and normally this is offered by the blood-vessels. The heart will beat more slowly and strongly in response to increased resistance, provided the resistance is not greater than the heart can overcome. In the latter case the heart is likely to dilate and its action becomes frequent and weak. The most common causes of abnormally high resistance are lack of elasticity and hardening of the walls of the arteries (known as arteriosclerosis), and such interference with the venous circulation as occurs in some forms of heart and kidney diseases. When the resistance is below normal, the heart beats become frequent and weak, a condition associated with surgical shock. Lessened resistance is due either to a relaxed condition of the blood-vessels or the loss of much blood, or of much fluid from the blood.

Disposition affects the heart beat as shown by the frequent heart action of persons of a nervous temperament, *i.e.*, those who respond to maximum number of sensory stimuli, and the reverse with those of a phlegmatic type, who fail to attend to many sensory stimuli.

It is probable that certain internal secretions affect the frequency and strength of the heart beat. Thyroid extracts when fed produce a faster and stronger pulse. *Thyroxin*, the active principle of the thyroid secretion is probably present in the blood. The partial removal of excessively active thyroid glands results in a slower heart rate.

Epinephrin from the adrenal glands, and a substance from the pituitary glands also affect the frequency and strength of the heart beat.

Distribution of blood to different parts of the body.—In health the quantity of blood contained in the body is always about the same, but the distribution varies, and is determined by the needs of the different parts. When the digestive organs are active, they need an extra supply of blood, which may be furnished in one or two ways, possibly both. The blood-supply to

[12] See page 154.

less active organs may be decreased, or the heart rate may be increased with consequent increase in the output of blood. Other causes may result in an increased supply of blood to an organ. If the skin is exposed to high temperatures the arterioles which bring blood to it are dilated, and the blood-flow near the surface is increased. This aids in the radiation of heat and control of body temperature. On the other hand, slight chilling causes contraction of the skin arterioles, and resulting paleness. The blood-supply to the brain is subject to adjustment in accordance with mental activity and emotional states. During normal sleep the blood-supply to the brain is reduced and this is accompanied by an increased supply to the muscles and skin regions. This has been demonstrated by the use of the plethysmograph,[13] an instrument designed to record changes in volume.

Authorities differ regarding the way in which these adjustments are made, but three factors are considered important: (1) the stimulation of vasoconstrictor nerves in the inactive parts of the body; (2) the stimulation of vasodilator nerves in the active parts of the body, and (3) the action of chemical and mechanical stimuli.

Factors maintaining arterial circulation.—The most important factors maintaining arterial circulation are (1) the pumping action of the heart,[14] (2) the extensibility and elasticity of the arterial walls, (3) the peripheral resistance in the region of the small arteries, and (4) the quantity of blood in the body.

The extensibility and elasticity of the arterial walls.—Each time the ventricles contract they force a certain amount of blood into arteries that are already full.[15] The extensibility of the arteries enables them to distend and receive this extra supply of blood. This period of distention corresponds to the contraction period of the heart. Just as soon as the force is removed, the elasticity of the arteries causes them to contract, and exerts such a pressure on the contained blood, that this blood is forced into the capillaries just rapidly enough to allow the arteries time to reach their usual size by the beginning of the next contraction

[13] Plethysmographs are of different forms, depending on the organ to be observed, but the principle is the same. The organ is enclosed in a case with rigid walls which has just one opening connected with a recorder by rigid tubing. The space in the interior of the instrument not filled by the organ may be filled with air or water. The connections are also filled with air or water. The recorder registers on a drum, the volume changes of the enclosed organ.

[14] See page 246.

[15] Estimated, from 2 to 3 ounces.

period of the heart. They thus serve not only as conducting tubes but exert a force that assists the heart in driving the blood into the capillaries.

The extensibility and elasticity of the arteries change with the health and age of the individual. Sometimes as the result of

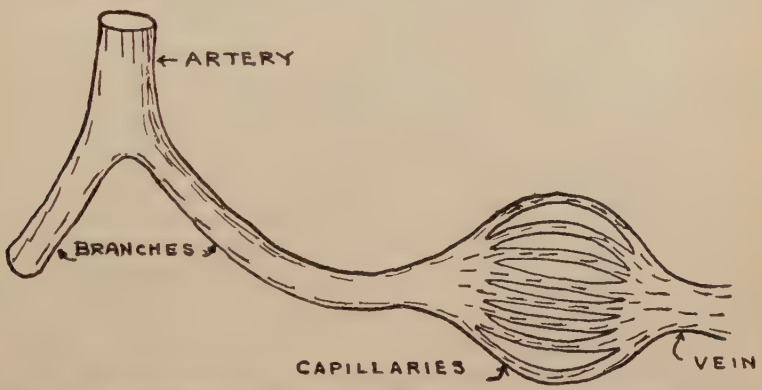


FIG. 161.—DIAGRAM TO ILLUSTRATE VARIATIONS IN VELOCITY OF BLOOD-FLOW. If a vessel divides into two branches, these will be individually of less cross-section than the main trunk, but united they will exceed it. Linear velocity will be lower in the branches than in the parent stock. The sum of the cross-sectional areas of the capillaries is greater than that of the artery or vein.

disease, and always as we grow older, the arterial walls grow stiffer and more rigid, and become less well adapted for the unceasing work they are called upon to perform. This condition is known as arteriosclerosis.

Peripheral resistance.—The walls of the arterioles and capillaries are not normally as extensile as the larger arteries, and as they are of smaller caliber and more numerous they offer intense resistance to the flow of blood from the arteries. In consequence the arteries are not entirely emptied and the blood enters the capillaries in a steady stream.

Quantity of blood.—It is evident that other things being equal the quantity of blood to be moved is an important factor. Except in cases of severe hemorrhage loss of blood is compensated for by a flow of liquid from the tissues into the blood-vessels.

Factors maintaining venous circulation.—The effect of the pumping action of the heart is not entirely spent in forcing the blood through the arteries and capillaries. A little force still remains to propel the blood back to the heart again, and the presence of valves keeps it flowing in the right direction, *i.e.*, toward the heart. The return flow is also favored by (1) the suction

action of the heart caused by the emptying of the auricles, (2) the heart and respiratory movements which cause continual changes of pressure in the thorax and abdomen, (3) the contractions of the skeletal and visceral muscles which exercise a massaging action upon the veins, and aided by the valves, propel the blood toward the heart.

The velocity of the blood-flow.—In all the large arteries the blood moves rapidly; in the capillaries very slowly; and in the veins the velocity is augmented as they increase in size, but never equals that in the aorta. The underlying principle is that in any stream the velocity is greatest where the cross-section of the channel is least, and lowest where the cross-section is greatest. The application of this principle requires that we regard the aorta as the narrowest and the capillaries as the widest part of the vascular system. This is readily admitted if we remember that it is the combined channels of millions of capillaries which we have to compare with the aorta. When a vessel divides, the sum of the cross-sections of the two branches is greater than that of the main trunk. Consequently the velocity will be reduced when an artery divides, and increased when two veins unite to make one. One reason why the velocity in the veins never equals that in the aorta is because the cross-section of the two venæ cavæ is greater than the cross-section of the single aorta. The actual service of the blood to the tissues is rendered in the capillaries (since the walls of the arteries and veins are too thick to permit of diffusion), hence the value of the slow passage.

The Pulse.—When the finger is placed on an artery which approaches the surface of the body and is located over a bone, a sense of resistance is felt, and this resistance seems to be increased at intervals corresponding to the heart beat, the wall of the artery at each heart beat being felt to rise up or dilate under the finger. This alternate dilatation and contraction of the artery constitutes the pulse; and in certain arteries which lie near the surface this pulse may be seen with the eye. When the finger is placed on a vein, very little resistance is felt; and, under ordinary circumstances, no pulse can be perceived by the touch or by the eye.

As each expansion of an artery is produced by a contraction of the heart, the pulse, as felt in any superficial artery, is a convenient guide for ascertaining the character of the heart's action.

Locations where the pulse may be felt.[16]—The pulse may be

[16] A graphic record of the rising and falling of the wall of an artery as the pulse waves traverse it can be made with a sphygmograph. By a lever the sphygmograph is made to write on a smoked drum.

counted wherever an artery approaches the surface of the body. These locations are:—

(1) The *radial* artery, on the thumb side of the wrist. On account of its accessible situation the radial artery is usually employed for this purpose.

(2) The *facial* artery, where it passes over the lower jawbone, which is about on a line with the corners of the mouth.

(3) The *temporal* artery, above and to the outer side of the outer canthus of the eye.

(4) The *carotid* artery on the side of the neck.

(5) The *brachial* artery, along the inner side of the biceps.

(6) The *femoral* artery, where it passes over the pelvic bone.

(7) The *dorsalis pedis*, on the dorsum of the foot.

Points to note in feeling a pulse.—In feeling a pulse the following points should be noted:

(1) The *frequency*, or the number of pulse beats per minute. As the pulse is due to the distention of the arteries caused by the blood forced into them when the ventricles contract, it really indicates the contractions of the ventricles. Normally this also indicates the contraction of the auricles, but in case of heart-block or fibrillation it would not. A pulse that is irregular in frequency shows variations, and is known as an *intermittent pulse*, *i.e.*, a pulsation is missed at regular or irregular intervals.

(2) The *force* or *strength* of the heart beat. Irregularity of force means that all the pulsations are not of equal strength. Irregularity of force or frequency is due to lack of tone of the cardiac muscle, or of the arteries. Occasionally the heart beat appears to be divided and two pulsations are felt, the second being weaker than the first. This is known as a *dicrotic* pulse. Each main pulse wave as it passes along the larger arteries has superimposed upon it a secondary wave, called the dicrotic wave, caused by the rebound of the aortic walls due to the closure of the semilunar valves which suddenly stops the blood from flowing back into the relaxing ventricles. Normally this dicrotic wave is so slight that it cannot be detected by the finger, but if the blood pressure is low and the arteries still elastic, the secondary wave may become so pronounced that it will be detected as a secondary beat.

(3) The *tension* or *resistance* offered by the artery to the finger. This is suggested by the amount of force required to obliterate the pulse, and is due to the pressure of blood within the vessels. This is discussed under Blood-Pressure.

Average frequency of the pulse.—The average frequency of the pulse in men is 60 to 70, in women, 65 to 80. Idiosyncrasies are frequently met with. A person in perfect health may have a much higher or a much lower rate. The relative frequency of the pulse and respirations is about four heart beats to one respiration.

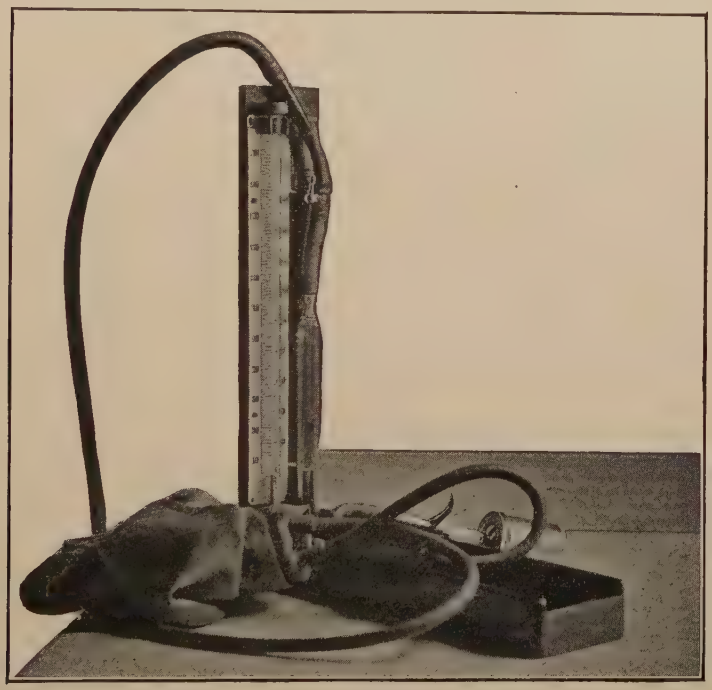
As a rule, the rapidity of the heart's action is in inverse ratio to its force. An infrequent pulse, within physiological limits, is usually a strong one, and a frequent pulse comparatively feeble; the pulse in fever or debilitating affections becoming weaker as it grows more rapid. As the pulse is an indication of the frequency of the heart beat, it follows that the factors which influence the heart beat will also influence the pulse. These have been discussed on page 249.

Blood-pressure.—We define blood-pressure as the pressure the blood exerts against the walls of the vessels in which it is contained. The term includes arterial, capillary, and venous pressure, but it is commonly applied to pressure existing in the large arteries. A vein is easily flattened under the finger; an artery offers a stronger resistance. This is an indication of a great difference between arterial and venous pressure. This difference is also shown when an artery and a vein are cut; the blood springs from the artery in a pulsating spurt indicating a high pressure, while the flow from the vein is continuous and even when copious "wells up" rather than "spurts out" indicating a low pressure.

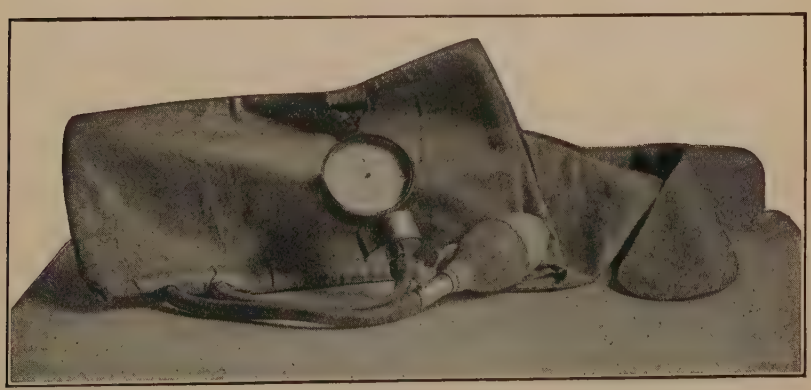
Blood-pressure is highest in the arteries during the period of ventricular contraction. This is systolic pressure. During ventricular diastole blood-pressure tends to fall and reaches a minimum just before the beginning of the next systole. The minimum is called diastolic pressure. Pressure in the arteries is high and fluctuating, slightly higher in the large trunks than in their branches; pressure in the veins is low and relatively constant. It must be higher in the small veins than in the large ones they unite to form, because the direction of the blood-flow is from the smaller to the larger ones. When the blood reaches the capillaries, the surface is multiplied and the friction increased. This offers an impediment to the flow, and the result is a *decided drop in the pressure.*

Blood-pressure is dependent upon (1) the force of the contraction of the ventricles, (2) the elasticity of the arteries and the tone of the muscular tissue in their walls, (3) the resistance offered to the flow of blood through the vessels. Minor factors

are (1) respiration and the accompanying changes in the chest cavity, (2) the amount of blood in the body, (3) the viscosity of the blood, and (4) gravity. Blood below the heart presses harder upon the vessels than it does above the heart, or on a level



A



B

FIG. 162.—SPHYGMOMANOMETERS. *A*, the mercury type. *B*, the spring or aneroid type.

with it. This is responsible for an exception to the rule, that venous pressure is low, because when standing the blood in the veins of the legs and feet, exert great pressure upon the vessel walls, hence the frequency of varicose veins in the lower limbs. Walking relieves this pressure because the contractions of the muscles force the blood upward in the veins, and the valves favor this movement.

Blood-pressure is increased above normal (1) when the elasticity of the arteries is reduced as in arteriosclerosis; (2) by various diseases of the heart, liver, and kidneys which interfere with the venous circulation; (3) by stimulation from the vasoconstrictor center in the medulla; and (4) usually by fever.

Naturally blood-pressure is reduced (1) when the heart beat is weak, (2) when the blood-vessels are relaxed, and (3) when the total quantity of blood in the vessels is reduced.

Method of determining blood-pressure.—It is customary to try the pulse at the wrist to determine whether an individual has high blood-pressure. If the radial artery is hard and incompressible it may indicate either that some change has occurred in the vessel, or that the pressure is high. If, however, the pulse is easy to obliterate with the fingers it is usual to find a low pressure.

Of late years many forms of apparatus have been devised by which a more accurate knowledge of this condition can be obtained. This apparatus is called a sphygmomanometer, and consists of a scaled column of mercury (manometer) marked in millimeters which is connected by rubber tubing with an elastic air bag contained in a leather cuff. The air bag is in turn connected with a small hand pump. Some instruments are constructed with a spring scale, instead of a manometer, but the principle is the same. The air bag contained in the cuff is buckled snugly about the arm just above the elbow so as to compress the brachial artery. By placing the finger upon the pulse at the wrist (as we inflate the bag) we finally reach a point where the pulse disappears, then the bag is very slowly deflated until the pulse can just be felt. The pressure in the bag, therefore, against the artery from the outside, as indicated on the instrument by the number of millimeters that the mercury is raised, is equal to the pressure which the blood exerts against the wall of the artery from the inside. This is known as the systolic pressure, and is the greatest pressure which the contractions of the heart (systole) cause in the brachial artery. Diastolic

pressure cannot be taken by this method. Another method of reading blood-pressure is to place a stethoscope over the brachial artery in the bend of the elbow. Blood-pressure is then indicated by sounds heard through the stethoscope. The bag is inflated as before, until all sounds cease. It is then slowly deflated until the pulse can just be heard. The reading on the mercury column or clock face at this time indicates systolic pressure. The deflation of the bag is then continued, and the reading on the mercury column or clock face just before the last sound of the disappearing pulse indicates diastolic pressure, which is the lowest pressure which the dilatation of the heart causes in the brachial artery.

Normal degree of blood-pressure.—The average systolic blood-pressure for a great many adult males is about 125 mm.; and for women about 115 mm. Individual variations are not uncommon, but 140 mm. for men, and 130 mm. for women is considered the normal upper limit. A systolic pressure of 150 mm. suggests hypertension. It varies during mental and muscular work and shows a tendency to fall during fatigue. Cold, drugs, etc., which constrict the arterial pulse may raise the blood-pressure. Heat, and the drugs of the vasodilator group like nitroglycerin, may lower it.

Pulse-pressure is the difference between the systolic and diastolic pressure, *viz.*, if the systolic is 115 mm. and the diastolic 75 mm. the pulse-pressure will be 40 mm. The pulse-pressure, is an indication of (1) how well the heart is overcoming the resistance offered it, (2) how successfully it is driving the blood to the periphery, and (3) the condition of the arteries, for in arteriosclerosis the pulse-pressure is high. Pulse-pressure varies and is dependent upon (1) the energy of the heart, (2) the elasticity of the blood-vessels, (3) the peripheral resistance, and (4) the quantity of circulating blood.

FETAL CIRCULATION

Certain structures are necessary to the performance of fetal circulation, but are of no use after birth. They are as follows:—

(1) **Foramen ovale.**—An opening between the two auricles. It furnishes direct communication between them.

(2) **Ductus arteriosus.**—A blood-vessel connecting the aorta and pulmonary artery.

(3) **Ductus venosus.**—A blood-vessel connecting the umbilical vein and the inferior vena cava.

(4) **The placenta and umbilical cord.**—The placenta is a mass of tissue rich in blood-vessels which is in close contact

with the lining of the uterus. The umbilical cord unites the placenta with the navel of the child. The cord is made up of two arteries and one large vein protected by Wharton's jelly. The arteries are branches of the arterial system of the fetus and carry blood from the fetus to the placenta where it is separated

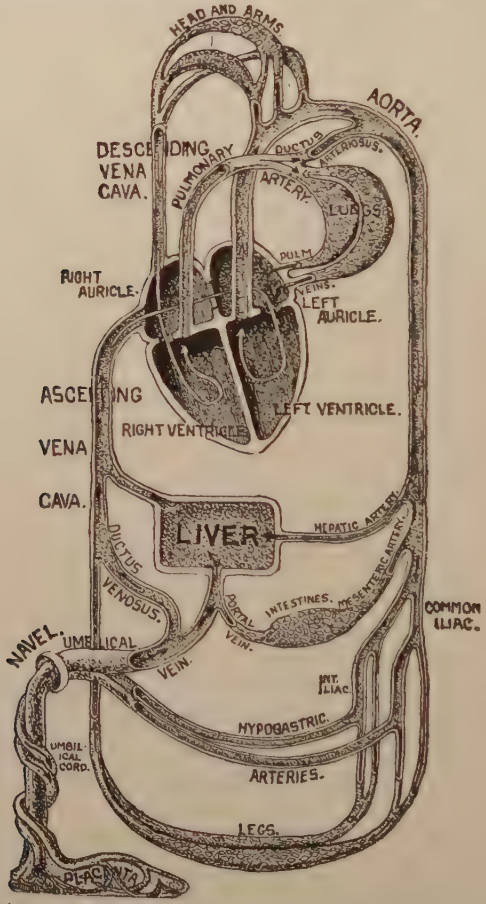


FIG. 163.—Diagram showing course of fetal circulation through hypogastric arteries, ductus venosus, ductus arteriosus, and the foramen ovale. (From The American Text Book on Obstetrics.)

by the thinnest of walls from the maternal blood in the blood-vessels of the uterus. The usual distinctions between arterial and venous blood cannot be recognized, as the blood of the fetus is never up to the arterial standard of the mother. The best blood is that which has been improved by effecting exchanges with the blood in the uterine vessels, and is carried from the placenta to

the fetus by the vein. By means of the placenta the fetus obtains oxygen, but it is more than a lung; it is the seat of the absorption of food, and the unloading of wastes. Consequently it represents a combination of organs, and serves as the respiratory, digestive, and excretory mechanism for the fetus.

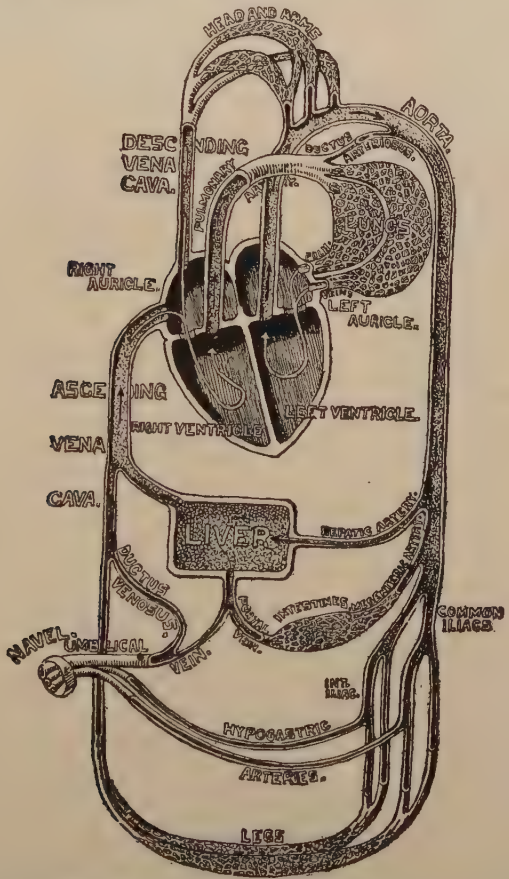


FIG. 164.—Diagram showing circulation of the blood after birth, with hypogastric arteries, ductus venosus, ductus arteriosus and foramen ovale in process of obliteration and pulmonary circulation greatly increased. (From The American Textbook on Obstetrics.)

Course of the blood.—The blood is carried from the placenta along the umbilical cord by the umbilical vein. Entering the fetus it is conveyed into the ascending vena cava partly through the liver but chiefly through the ductus venosus, which connects these two vessels. From the ascending vena cava it enters the right auricle, passes through the foramen ovale into the left

auricle, thence into the left ventricle, and out through the aorta, which distributes it principally to the upper extremities. The blood from the head and upper extremities returns by the descending vena cava to the right auricle, then passes into the right ventricle, and out through the pulmonary artery to the lungs. As the lungs in the fetus are solid, they require very little blood (only for nutrition), and the greater part of the blood passes through the ductus arteriosus into the descending aorta, where, mixing with the blood delivered to the aorta by the left ventricle it descends to supply the lower extremities of the fetus. The chief portion of this blood is carried to the placenta by the two umbilical arteries, but a small amount passes back into the ascending vena cava and mixes with the blood from the placenta.

From this description of the fetal circulation, it follows:—

1. That the placenta serves the purpose of a respiratory, nutritive, and excretory organ.

2. That the liver receives blood directly from the placenta; hence the large size of this organ at birth.

3. That the blood from the placenta passes almost directly into the arch of the aorta, and is distributed by its branches to the head and upper extremities; hence the large size and perfect development of these parts at birth.

4. That the blood in the descending aorta is chiefly derived from that which has already circulated in the upper extremities, and, mixed with only a small quantity from the left ventricle, is distributed to the lower extremities; hence the small size and imperfect development of these parts at birth.

Changes in the vascular system at birth.—From the foregoing description it is obvious that at birth very important changes must take place:—

1. The blood clots in the umbilical vein, between the usual ligature and the liver, also in the ductus venosus. The blood-clot becomes organized and these two vessels become obliterated.

2. As respiration commences, the blood traverses the pulmonary arteries, and then returns to the heart by the pulmonary veins; this raises the blood-pressure in the left auricle, and causes the valve over the foramen ovale to close.

3. The blood in the ductus arteriosus clots, the clot organizes, and the ductus arteriosus becomes a fibrous cord.

4. The blood in the hypogastric arteries also clots, the clots organize, and these vessels become obliterated.

Occasionally some of the embryonic by-passes fail to close, and

so much venous blood enters the arterial system that a *blue baby* is the result. In such instances the child suffers from malnutrition and the chances for survival are slight.

SUMMARY

Blood Vascular System

- **Pulmonary Circulation**
  - Right ventricle, then pulmonary arteries to lungs. Capillary system. Return by pulmonary veins to left auricle.
  - **Purpose**—To increase oxygen and decrease carbon dioxide to standard amount.
- **General or Systemic Circulation**
  - Left ventricle, then by means of aorta and its branches to all parts of the body. Capillary system. Return by veins which empty into superior and inferior venæ cavæ. These empty into right auricle.
  - Thought to require about 23 sec. for circuit of medium length.
  - **Purpose**
    - Carry, and give up to the cells
      - Oxygen.
      - Nutritive materials.
    - Take from the cells
      - Excess carbon dioxide.
      - Waste products.

Heart

- **Pumping Action**
  - Muscles contract and lessen capacity of auricles and ventricles, thus forcing blood into arteries.
- **Wave of Contraction**
  - Starts at sinu-auricular node, transmitted to bundle of His, which in turn transmits it to the ventricles.
  - *Heart-block*—Condition resulting from damage to bundle of His and consequent failure to transmit impulses from auricles to ventricles. Rate of auricular and ventricular contraction different.
  - *Fibrillation*—Condition resulting from pathological changes in bundle of His which interfere with passage of impulses to all the cavities of the heart. Contractions of different parts not coördinated.
- **Heart Beat**
  - Coördinated contraction of cardiac muscle.
  - 1. **Systole**—Contraction
  - 2. **Diastole**—Dilatation
  - 3. **Rest**—Quiescent
    - Cardiac cycle, 72 per min.
    - Occupies about 0.8 of a second.
    - Diastole and rest period about 0.04 sec.
- **Heart Beat**
  - **Cause**
    - Neurogenic theory makes contained nerves responsible. Myogenic theory makes automaticity responsible.
    - Stimulated by chlorides
      - Sodium.
      - Potassium.
      - Calcium.
      - Magnesium.
    - Innervation is regulatory.
      - Inhibitory from vagus nerve.
      - Accelerator from sympathetic system.
- **Heart Sounds**
  - Lubb
    - Vibrations caused by closure of auriculoventricular valves and the contraction of ventricles.
  - Dup
    - Vibrations caused by closure of semilunar valves.
  - Other sounds have been described.

Factors affecting the frequency and strength of the heart's action

- **Temperature of blood** — Elevated temperature increases rate, and low temperature decreases rate of heart beat.
- **Characteristics of Heart Muscle**
  - Tone
  - Irritability
  - Conductivity
  - Contractility

  Anything affecting these factors likely to affect frequency and force of heart's action. Cardiac muscle specially dependent on property of conductivity.
- **Physical**
  - Size—Frequency of heart beat is in inverse proportion to size of animal. Elephant 25 per minute, mouse 175 per minute.
  - Sex—Frequency of heart beat higher in women than in men.
  - Age
    - At birth about 140 per minute.
    - At three years about 100 per minute.
    - In youth about 90 per minute.
    - Adult life about 75.
    - Extreme old age 75-80.
  - Posture
    1. Erect posture—about 80.
    2. Sitting position—about 70.
    3. Recumbent—about 66.
  - Muscular Exercise
    1. Activity of the cardiac centers in the medulla.
    2. Reaction of blood stimulates respiratory center.
    3. Pressure of contracting muscles sends more blood to the heart.
  - Resistance
    - Normally heart requires certain amount of resistance—offered by blood-vessels.
    - Normal amount—heart action slow and strong.
    - Increased amount—heart action frequent and weak.
  - Condition of blood-vessels
    - Arteriosclerosis—loss of elasticity of arteries.
    - Relaxation or loss of tone due to loss of blood or much fluid from the blood.
  - Disposition
    - Nervous temperament—pulse rate high.
    - Phlegmatic temperament—pulse rate low.
- **Internal Secretions**
  - The thyroid.
  - The adrenals.
  - The pituitary.

Distribution of blood to different parts of the body

Quantity of blood in body usually about the same but quantity in any given part adjusted to needs.

Adjustments dependent on
1. Stimulation of vasoconstrictor nerves in inactive parts.
2. Stimulation of vasodilator nerves in active parts.
3. Action of mechanical and chemical stimuli.

Factors Maintaining Arterial Circulation
1. Pumping action of the heart.
2. The extensibility and elasticity of the arterial walls.
3. Peripheral resistance.
4. The quantity of blood in the body.

Factors Maintaining Venous Circulation
1. Some force due to pumping action of the heart.
2. Suction action of the heart.
3. Changes of pressure in thorax and abdomen due to heart and respiratory movements.
4. Contractions of the skeletal muscles.

Velocity of Blood-flow
- Arteries—blood moves rapidly in large arteries, more slowly in smaller ones.
- Capillaries—blood moves very slowly.
- Veins—blood moves slowly in small veins, more rapidly in larger veins, but never as rapidly as in arteries.

Pulse
- Alternate contraction and expansion of artery, corresponding to heart beat.
- **Locations where Pulse may be Counted**
  - Radial artery.
  - Facial artery.
  - Temporal artery.
  - Carotid artery.
  - Brachial artery.
  - Femoral artery.
  - Dorsalis pedis.
- **Points to Note**
  - Frequency.
  - Force or strength.
  - Tension or resistance.
- **Pulse Rate**
  - Factors which influence heart beat also influence pulse.
  - Average
    - 60-70 in men.
    - 65-80 in women.
  - Ratio of pulse to respiration is about 4 to 1.

Blood-Pressure
- Pressure blood exerts against walls of vessels.
- Arterial
  - High and fluctuating.
  - Not uniform
    1. Highest during ventricular contraction = sytolic pressure.
    2. Lowest before beginning of next systole = diastolic pressure.
    3. Increases with age.
    4. Decreases if heart or arteries lose their tone.
- Venous—Low and constant.
- **Dependent upon**
  - Strength of the heart beat.
  - Elasticity of the arteries.
  - Resistance offered.
  - Minor factors
    - Respiration and resulting changes in chest cavity.
    - Amount of blood in body.
    - Viscosity of blood.
    - Gravity.
- **Increased by**
  - Arteriosclerosis.
  - Heart, liver and kidney diseases which interfere with venous circulation.
  - Stimulus from vasoconstrictor center in the medulla which constricts arteries and veins.
  - Fever.
- **Reduced**
  - When the heart beat is weak.
  - When the blood-vessels are relaxed.
  - When the total quantity of blood in the vessels is reduced.
- **Determined by use of sphygmo-manometer**
  1. Scaled column of mercury connected with air bag.
  2. An elastic air bag contained in a cuff of leather.
  3. Air bag also connected with hand pump.
  4. Some types have stethoscope.

Blood-Pressure

- Systolic—greatest pressure which the contraction of heart causes in brachial artery.
- Average systolic
  - For men 125 mm.
  - For women 115 mm.
- Diastolic—lowest point to which blood-pressure drops between beats.
- Varies
  - During mental and muscular work and shows a tendency to fall during fatigue.
  - Cold, drugs, etc., which constrict arterial pulse may raise.
  - Heat, drugs of the vasodilator group may lower.

Pulse-Pressure

- Difference between systolic and diastolic pressure.
- Indicates
  - How well the heart is overcoming resistance offered.
  - How successfully it is driving blood to the periphery.
  - Condition of arteries.
- Dependent upon
  - Energy of heart.
  - Elasticity of the blood-vessels.
  - Peripheral resistance.
  - Quantity of blood circulating.

Fetal Circulation

1. Direct communication between right and left auricle by means of foramen ovale.
2. Direct communication between umbilical vein and inferior vena cava. Ductus venosus.
3. Direct communication between pulmonary artery and aorta. Ductus arteriosus.
4. Oxygen and nutritive substances obtained from placenta.
5. Waste eliminated by placenta.

Changes in Vascular System at Birth

1. Umbilical vein and ductus venosus become obliterated.
2. Respiration stimulates pulmonary circulation; this raises the blood-pressure in left auricle, and closes foramen ovale.
3. Ductus arteriosus becomes a fibrous cord.
4. Hypogastric arteries become obliterated.

CHAPTER XIV

LYMPH.—THE LYMPH VASCULAR SYSTEM

The blood does not come into immediate contact with the cells but is separated from them by the walls of the capillaries. This necessitates a medium of exchange between the blood and the cells. Lymph serves this purpose.

Sources of lymph.—The plasma of the blood is constantly making its way through the thin walls of the capillaries into such spaces as exist between the cells forming the tissues. Some physiologists claim that the combined action of the physical processes of filtration, diffusion and osmosis,[1] is sufficient to account for the formation of lymph. Others claim that in addition it is necessary to assume an active secretory process on the part of the endothelial cells composing the capillary walls. This plasma plus the leucocytes that have left the vessels by migration make up the lymph.

- **Lymph**
  - Intercellular—Tissue fluid lies between all cells.
  - Intravascular
    - Lymph in the lymph-vessels.
    - Chyle.
    - Peritoneal fluid.
    - Pleural fluid.
    - Pericardial fluid.
    - Cerebrospinal fluid.
    - Synovial fluids and fluids in bursæ.
    - Endo[2]- and perilymph of the internal ear.
    - Fluids of eye.

It has been suggested that the term lymph be applied to the fluid contained in the lymphatic channels only, while that part of it found in the tissue-spaces, bathing the individual cells, be designated tissue-fluid. The reason given for this distinction is that the lymph in the lymph-vessels differs in composition from the fluid found in the tissues. On the other hand, it is argued that lymph originates in all parts of the body, and all types of lymphatic fluids contribute to its formation. Consequently it seems desirable to class as lymph the fluids found in the lymph-vessels; in the tissues; in the different serous-spaces of the body, *i.e.*, the pericardial, pleural and peritoneal cavities; and in the spaces of the cerebrum, spinal cord, eyes, ears and joints. In addition

[1] For an explanation of osmosis and dialysis see page 268.

[2] See page 472.

the lymph that fills the lacteals of the intestinal villi is milky in appearance due to the absorption of fat, and is called *chyle*.

Lymph.—The composition of lymph is similar to that of the plasma from which it is derived. It is a colorless or yellowish fluid possessing an alkaline reaction, a salty taste, and a faint odor.

When examined under the microscope, it is seen to consist of a clear liquid with cells floating in it. Its resemblance to the blood-plasma is indicated in the following table:—

Blood	Lymph
Specific gravity about 1.055	Specific gravity varies between 1.015 and 1.023
Contains red cells	May contain red cells[3]
Contains white cells	Contains white cells
Contains blood-platelets	Does not contain blood-platelets
A high content of blood-proteins	A lower content of blood-proteins
A low content of waste products	A higher content of waste products
A high content of nutrients	A lower content of nutrients
Normally—clots quickly and firmly	Clots slowly and does not form a firm clot

Function of the lymph.—The lymph bathes all portions of the body not reached by the blood. It delivers to the cells the material each cell needs to maintain its functional activity, and picks up and returns to the blood the products of this activity, which products may be simple waste, or matters capable of being made use of by some other tissue. There is thus a continual interchange going on between the blood and the lymph. This interchange is effected by means of osmosis and dialysis.

Osmosis and dialysis.[4]—The lymph becomes altered by the metabolic changes of the tissues which it bathes, and we have three different fluids, separated by the moist membranes which form the walls of the blood-vessels and lymphatics, the blood inside the capillary walls, the lymph in the tissues outside the walls of the blood-vessels, and the lymph in the lymph channels. Some of the constituents of the blood pass into the lymph in the tissues; some of the constituents of the lymph pass into the blood directly, and some into the lymphatics. The capillary walls and walls of the lymph-vessels are permeable and allow water molecules (solvent), and molecules of substances in solution (solute) to pass through. Diffusion of this kind is dependent on differences in concentration of the fluids.

In consequence of the different wants and wastes of different

[3] Red cells are frequently found but it is believed they are not a normal or constant element of lymph, but rather an accidental constituent.

[4] See page 397.

tissues at different times, both the lymph and blood must vary in composition in different parts of the body. But the loss and gain is so fairly balanced that the average composition is pretty constantly maintained.

The chyle, or lymph of digestion, absorbs nutrient materials (mostly fat) from the intestines and pours this food into the blood current, to be distributed to all parts of the body.

LYMPH VASCULAR SYSTEM

As the process of lymph formation is continual, it follows that edema would result from the accumulation of lymph if some system of drainage were not provided to return the lymph to the blood. This drainage system is called the lymph vascular system.

- **Lymph Vascular System**
  - **Lymph-vessels**
    - Lymph capillaries.
    - Lymphatics.
    - Thoracic duct.
    - Right lymphatic duct.
    - Lacteals.
  - **Expanded Lymph-spaces**
    - Pleural cavity.
    - Pericardial cavity.
    - Peritoneal cavity.
    - Meningeal spaces.
    - Lymph-spaces of eye and ear.
    - Synovial bursæ.
  - **Lymph-nodes**

Lymph vessels.—The plan upon which the lymphatic system is constructed is similar to that of the blood vascular system, if we omit the heart and the arteries. In the tissues we find the closed ends of minute microscopic vessels, called *lymph capillaries*, which are comparable to, and often larger than, the blood capillaries. The distribution of these lymph capillaries is comparable to that of blood capillaries as they are found in every part of the body except cartilage, hair, nails and cuticle. These lymph capillaries unite to form larger vessels called *lymphatics*, which are comparable to the veins. The lymphatics continue to unite and form larger and larger vessels until finally they converge into two main channels, (1) the thoracic duct, and (2) the right lymphatic duct.

The thoracic duct.—The thoracic duct begins at the second lumbar vertebra and ascends upward to the seventh cervical. It lies in front of the bodies of the vertebræ, gradually inclining towards the left, until, on a level with the seventh cervical vertebra, it turns outward and arches downward and forward to terminate in the innominate vein at the point of junction of the left internal jugular and left subclavian.

It is from fifteen to eighteen inches (38—45 cm.) long in the adult, and is about the size of a goose quill. It receives the lymph from the left side of the head, neck, and chest, all of the abdomen and both lower limbs, also the chyle from the lacteals. It is dilated below, where it receives the lymph from the lower limbs and the chyle from the lacteals, the dilatation being known as the chyle cistern (receptaculum chyli). (See Fig. 158.)

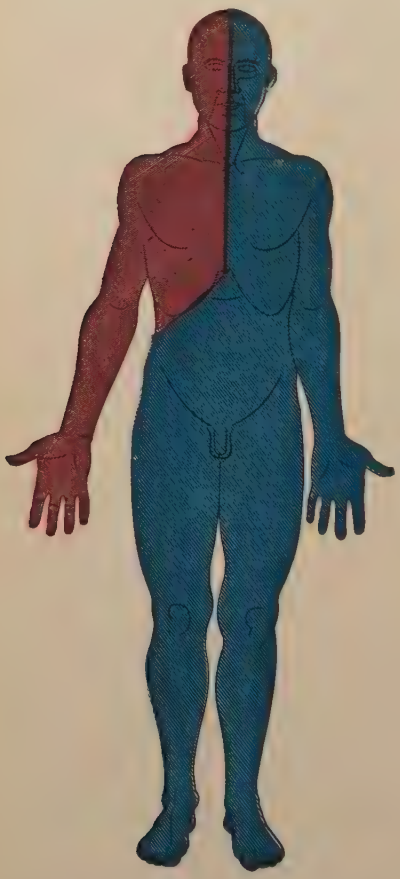


FIG. 165.—THE REGIONS WHOSE LYMPH FLOWS INTO THE RIGHT LYMPHATIC DUCT ARE SUGGESTED BY THE RED AREA; THOSE WHICH ARE TRIBUTARY TO THE THORACIC DUCT BY THE BLUE AREA. (Gerrish.)

The right lymphatic duct.—The right lymphatic duct is a short vessel, usually about one-half inch (1.25 cm.) in length. It pours its contents into the innominate vein at the junction of the right internal jugular and subclavian veins.

The lymphatics from the right side of the head, neck, the right arm, and the upper part of the trunk enter the right lymphatic duct. The parts drained by each are suggested by Fig. 165.

Structure of the lymph-vessels.—The lymphatics resemble the veins in their structure as well as in their arrangement. The smallest have but a single coat of endothelioid cells, having a peculiar dentated outline. The larger vessels have three coats similar to veins, except that they are so thin as to be transparent, and are more abundantly supplied with valves. The valves are constructed and arranged in the same fashion as those of the veins but follow one another at such short intervals that, when dis-

tended, they give the vessel a beaded or jointed appearance. They are usually wanting in the smaller networks. The valves allow the passage of material from the smaller to the larger lymphatics, and from these into the veins, but obstruct the flow in the opposite direction.

Classification of lymphatics.—The lymph, like the blood in the veins, is returned from the limbs and viscera by a superficial and a deep set of vessels. The superficial lymphatic vessels are placed immediately beneath the skin, and accompany the superficial veins. In certain situations they penetrate the deep fascia and join the deep lymphatic vessels which lie in the submucous tissue throughout the whole length of the gastropulmonary and genito-urinary tracts, and in the subserous tissue of the thoracic and abdominal cavities. The deep lymphatics, fewer in number and larger than the superficial, accompany the deep blood-vessels.

FIG. 166. — VALVES OF THE LYMPHATICS.

Lacteals.—The lymphatics that have their origin in the villi of the small intestine are called lacteals. During the period of intestinal digestion they are filled with chyle, which has a white aspect, due to fat absorbed from the food, and suspended in it like oil in milk. After fasting, the lacteals contain lymph which differs very little from the lymph found in the ordinary lymphatics.

Expanded lymph-spaces.—A close relationship exists between the lymphatics and the serous cavities of the body, *i.e.*, pleural, pericardial and peritoneal cavities, the meningeal spaces, lymph-spaces of eye and ear, and the synovial bursæ. These cavities are lined by endothelium through which the lymph transudes by osmosis.

Function of the lymphatics.—The function of the lymphatics is to carry from the tissues to the veins all the materials which the tissues do not need. Functionally they may be considered between the capillaries and the veins, as they gather up the lymph which exudes through the thin capillary walls, and return it to the innominate veins. Here it becomes mixed with the blood, enters the superior vena cava, and then the right auricle of the

heart. The function of the lacteals is to help in the absorption of digested food, especially fats.

Lymph-nodes.—The lymph-nodes are numerous round or ovoid bodies placed in the course of the lymphatics. They vary in size from a pinhead to an almond. A lymph-node is covered by a thin capsule consisting of fibrous and in some cases muscular tissue. This capsule sends fibrous bands called trabeculæ (little beams) into the substance of the node, and divides it into irregular spaces, which communicate freely with each other. The irregular spaces are occupied by a mass of lymphoid tissue, which, however, does not quite fill them as it never touches the capsule or trabeculæ, but leaves a narrow interval between itself and them. It looks as if the pulp had originally filled the framework and then shrunk away slightly on all sides. The spaces thus left form channels for the passage of the lymph, which enters by afferent vessels, and, after circulating through the node, issues by efferent vessels. The trabeculæ support a free supply of blood-vessels.

FIG. 167.—LACTEALS AND LYMPHATICS, DURING DIGESTION. (Dalton.)

Location of nodes.—There is a superficial and a deep set of nodes just as there is a superficial and a deep set of lymphatics and veins. Occasionally a node exists alone, but they are usually in groups or chains at the sides of the great blood-vessels. They are found in great numbers in the neck, thorax, axilla, groin, mesentery, and alongside of the aorta, inferior vena cava, and the iliac vessels. A few are found in the popliteal space and in the arm as

far as the elbow, but none farther down the leg or forearm. They are usually named from the position in which they are found in the body, *viz.*, cervical in the neck, thoracic in the thorax, axillary in the axilla, inguinal in the groin, mesenteric in the mesentery.

Function of the lymph-nodes.—The lymph-nodes serve two important purposes:—

(1) *Multiplication of lymphocytes.*—In its passage through the node the lymph takes up fresh lymphocytes, which are continually multiplying by cell division in the substance of the node, which is considered the birth-place of these cells.

(2) *As filters for the lymph.*—In this way they act as safety-valves and serve to retard the spread of infection through the body. If any portion of the body is infected, the infection may be carried by the lymphatics to their special nodes. There its course is stopped. Foreign substances such as bacteria are caught in the sieve-like network of lymphoid tissue and the lymphocytes together with the phagocytes contained in the lymph try to destroy them. Unless the infection is very severe the chances are against the bacteria on account of the large number of white cells present in the nodes. If the bacteria win out, the infected material is discharged into the lymph and ultimately into the blood, unless the lymph traverses other nodes where the white cells are more successful.

FIG. 168.—A LYMPH-NODE WITH ITS AFFERENT AND EFFERENT VESSELS. (Gerrish.)

Factors controlling the flow of lymph.—The onward progress of the lymph from the tissues to the veins is maintained chiefly by three things.

(1) **Differences in pressure.**—The lymph in the tissues is under greater pressure than the lymph in the lymph capillaries, and the pressure in the larger lymphatics near the ducts is much less than in the smaller vessels. Consequently we may consider that the lymphatics form a system of vessels leading from a

region of high pressure, *viz.*, the tissues, to a region of low pressure, *viz.*, the interior of the large veins of the neck.

(2) **Muscular movements and valves.**—The muscular movements of the body compress the lymphatics and force the lymph on in the proper direction. The numerous valves prevent a return flow in the wrong direction.

(3) **Respiration.**—During each inspiration the pressure on the

FIG. 169.—THE LYMPH-NODES OF THE NECK AND UPPER PART OF THE THORAX. (Gerrish.)

thoracic duct is less than on the lymphatics outside the thorax, and the lymph is accordingly "sucked" into the duct. During the succeeding expiration the pressure on the thoracic duct is increased, and some of its contents, prevented by the valve from escaping below, are pressed out into the innominate veins.

Edema.—The lymph in the various tissues of the body varies in amount from time to time, but under normal circumstances remains fairly constant. Under abnormal conditions, these limits may be exceeded, and the result is known as edema, or dropsy.

FIG. 170.—THE LYMPH-NODES AND VESSELS OF THE UPPER LIMB. (Gerrish.)

FIG. 171. — THE LYMPH-NODES AND VESSELS OF THE LOWER LIMB. (Gerrish.)

Similar excessive accumulations may also occur in the larger lymph spaces, the serous cavities.

Among the possible causes of edema are:—

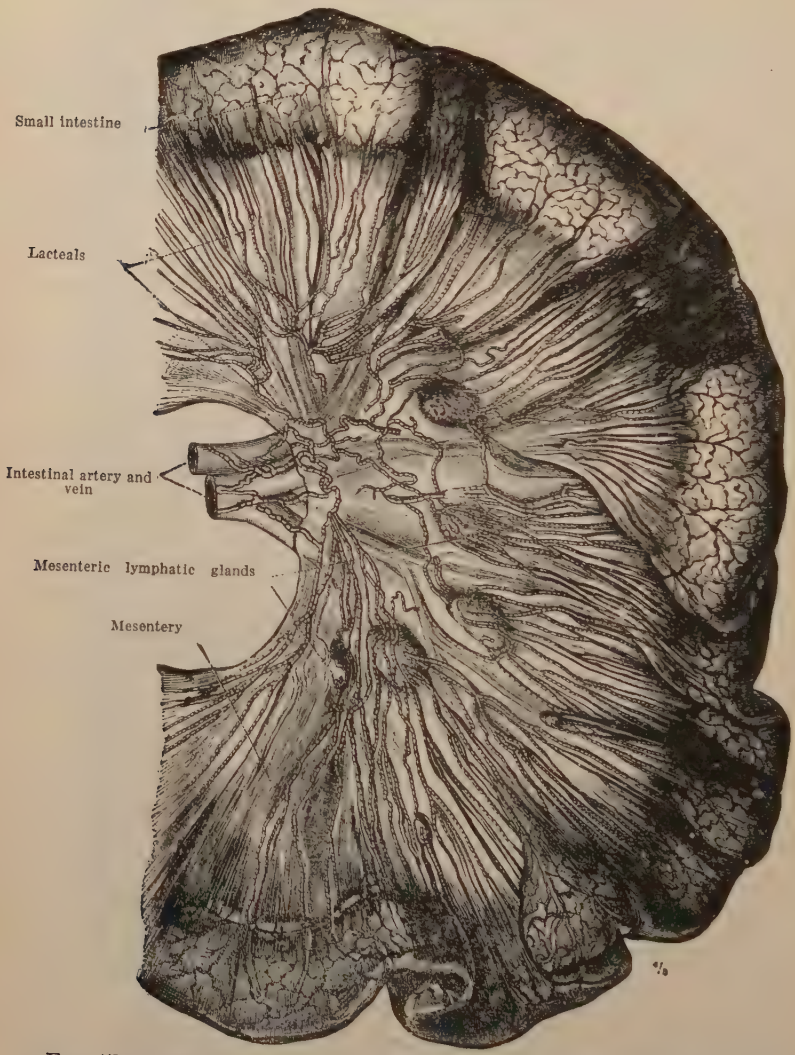


FIG. 172—THE LACTEALS AND THE MESENTERIC LYMPHATIC NODES, DEMONSTRATED IN A LOOP OF SMALL INTESTINE BY INJECTION WITH METALLIC MERCURY. (Toldt, Atlas of Human Anatomy.)

(1) An excessive formation, the lymph gathering in the tissues faster than it can be carried away by a normal flow.

(2) Any obstruction to the flow of lymph from the tissues.

SUMMARY

- **Lymph**
  - **Sources of lymph**
    - Physical processes of
      - Filtration.
      - Diffusion.
      - Osmosis.
    - Active secretory process on part of endothelial cells.
  - **Types**
    - Intercellular—Tissue fluid throughout the body.
    - Intravascular
      - Lymph in the lymph-vessels.
      - Chyle.
      - Peritoneal fluid.
      - Pleural fluid.
      - Pericardial fluid.
      - Cerebrospinal fluid.
      - Synovial fluids and fluids in bursæ.
      - Endo- and perilymph of the internal ear.
      - Fluids of eye.
  - **Description**
    - Colorless or yellowish liquid.
    - Alkaline reaction when tested with litmus.
    - Salty taste. No odor.
    - Consists of blood plasma plus leucocytes.
    - Specific gravity varies between 1.015 and 1.023.
    - Contains a low content of blood-proteins.
    - Contains a low content of nutrients.
    - Contains a high content of waste products.
    - Clots slowly, does not form a firm clot.
  - **Functions**
    - Lymph acts as middleman between the blood and the tissues.
    - Carries nourishment *from* blood to tissues.
    - Carries waste from tissues to blood.
    - Dependent upon osmosis and dialysis.
- **Lymph Vascular System**
  - **Lymph-vessels**
    - Lymph capillaries.
    - Lymphatics.
    - Thoracic duct.
    - Right lymphatic duct.
    - Lacteals.
  - **Expanded lymph-spaces.**
  - **Lymph-nodes**
- **Lymph-Vessels**
  - **Lymph Capillaries**
    - Origin in tissues.
    - One coat of endothelium—dentated.
    - Start as microscopic lymph capillaries, unite to form lymphatics. Comparable to formation of veins.
    - Distribution comparable to blood capillaries.
  - **Lymphatics**—three coats—numerous valves.
  - **Thoracic Duct**
    - 15 to 18 in. long. Size of goose-quill.
    - In front of vertebra from 2d lumbar to 7th cervical.
    - Has three coats—numerous valves.
    - Dilatation at lower portion called chyle cistern.
    - Receives lymph from left side of head, neck, and chest, left arm, all of abdomen, and both lower limbs. Receives chyle from lacteals.
    - Pours lymph and chyle into left innominate vein.
  - **Right Lymphatic Duct**
    - About ½ in. long.
    - Receives lymph from right side of head, neck, and chest, also right arm.
    - Pours lymph into right innominate vein.

- **Lymph-Vessels**
  - **Classification**
    - **Superficial**—beneath skin, accompany superficial veins.
    - **Deep**—accompany deep blood-vessels.
  - **Lacteals**
    - Lymphatics of the intestines.
    - Many originate in villi of small intestine.
    - Contain
      - During digestion—chyle.
      - During period of fasting—lymph.
    - Absorb fatty substances.
  - **Expanded Lymph-Spaces**
    - Pleural cavity.
    - Pericardial cavity.
    - Peritoneal cavity.
    - Meningeal spaces.
    - Lymph-spaces of eye and ear.
    - Synovial bursæ.
  - **Function**—Drain off lymph from all parts of the body and return it to the innominate veins.
- **Lymph Nodes**
  - **Description**
    - Shape
      - Round.
      - Ovoid.
    - Size varies from pinhead to almond.
    - Outer capsule—Fibrous and muscular tissue.
    - Interior divided into irregular spaces like sponge.
    - Spaces partially filled with lymphoid tissue. Communicating channels for lymph, which enters by afferent, leaves by efferent vessels.
    - Are well supplied with blood.
  - **Location**
    - Superficial and deep set.
    - Usually arranged around blood-vessels.
    - Neck, thorax, axilla, groin, mesentery.
    - In the arms as far as elbows.
    - In the legs as far as popliteal space.
    - Usually name indicates location.
  - **Function**
    1. Multiplication of lymphocytes.
    2. Filters—preventive and protective.
- **Factors controlling flow of lymph**
  - Difference in pressure.
  - Muscular movements and valves.
  - Respiration.
- **Edema**
  - Accumulation of lymph in the tissues.
  - **May be caused by**
    1. Excessive formation.
    2. Obstruction to flow of lymph from tissues.

CHAPTER XV

GLANDS; GLANDS WITH DUCTS; ENDOCRIN OR DUCTLESS GLANDS

Studies in medicine, biology, physics and chemistry reënforce the idea that the human body is a unified whole, or as we have put it, there is coöperation, coördination and integration of the different systems of the body, of the different organs constituting these systems, and of the different tissues and cells. This coördination and integration are secured in two ways: (1) by impulses from nerve cells or control by the nervous system; (2) by substances which circulate in the blood and effect control by influencing changes which are essential to the well-being of the body. The effect produced by these substances is often on an organ distant from the place of their origin.

GLANDS

A gland is a secreting organ, or an organ which abstracts certain materials from the blood and makes of them a new substance.

The new substance may be intended for use in the body, or to be eliminated as waste. All living cells have the power to withdraw from the blood the material they need for their own metabolic activities and to secrete substances which enter the blood. But certain aggregations of cells secrete specific named substances either into cavities in the body, or on the surface of the body, or into the blood-stream,[1] and are named glands. Secretion is the special function of glandular cells, *i.e.*, it is their share of the work of the coöperative community to which we have likened the body, and is carried on for the welfare of the whole. The power of secretory cells to perform their function, *i.e.*, take from the blood or lymph the materials to make new substances is dependent upon: (1) chemical factors, (2) such physical factors as osmosis,[2] dialysis and the permeability of membranes, and (3) all the energy changes associated with metabolic activities within the cells. The substances produced by glands are named secretions and excretions.

Secretion.—A new substance, the product of a gland, elab-

[1] Ductless glands, see page 283.

[2] See page 268.

orated from the blood by cell action, and intended for use in the body, is a secretion.

Excretion.—An excretion is a secretion, except that the excretion is generally formed to be thrown out of the body, whereas the secretion is intended for use in the body. It therefore follows that all excretions are first secretions, and with the exception of urine all excretions are made use of before they are eliminated. For instance, bile serves several purposes before it is eliminated. Urine, on the other hand, is a secretion, but is formed only to be eliminated.

Classification.—If classified according to function, glands are of two kinds.

1. Secretory, or those that form secretions.
2. Excretory, or those that form excretions.

The secretory glands are of two types, one type provided with ducts through which the secretion they produce is discharged, and a second type called ductless or endocrin[3] glands, that possess no ducts. The secretion produced by the ductless glands is discharged into the blood, either directly or indirectly by way of the lymphatics. Based on the difference in structure and mode of liberating their secretions, secretory glands are divided into two groups, those producing external secretions, and those producing internal secretions.

External secretions.—This term is used to designate those secretions of glandular tissues which are carried to their destination by a duct. All of the digestive fluids—saliva, gastric fluid, pancreatic fluid, bile, and intestinal fluid—are examples of external secretions, because they are carried off from the respective glands in which they are formed by means of ducts, and their action is localized to the parts reached by the ducts.

Internal secretions or endocrins.—This term is used to designate those secretions of glandular tissues which are *not* carried off to the exterior by a duct, but instead are discharged into the blood or lymph. The conception is that probably all the ductless glands form secretions which are called internal secretions or endocrins. It has also been shown that not only the ductless glands, but some at least of the typical glands provided with ducts, may give rise to internal secretions. For example, the pancreas forms the pancreatic fluid and discharges it by means of a duct into the small intestine. In addition, the pancreas forms an internal secretion which passes into the blood.

[3] Spelled also endocrines. From *endon*, within; *krino*, I separate.

GLANDS WITH DUCTS

Size and structure.—The simplest form of a gland may consist of just one cell, or may be a mere depression on the surface of a membrane, or may consist of a vast number of secreting recesses. The liver and pancreas are examples of the latter. No matter what the size or shape may be, all glands have three essential characteristics: (1) epithelial cells which are the active secreting agents, (2) a liberal blood-supply from which the material for the secretion is drawn, (3) they are under the direct control of the nervous system and secretion is their response to stimulation, just as contraction is the response

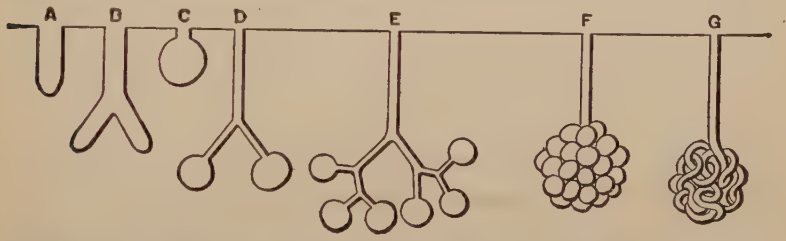


FIG. 173.—DIAGRAM SHOWING DEVELOPMENT OF GLANDS: *A*, a mere dimple in the surface or a simple tubular gland; *B*, enlargement by division or a branched tubular gland; *C*, enlargement by dilatation or a saccular gland; *D*, a combination of *B* and *C* or a branched saccular gland; *E*, a compound saccular or a racemose gland; *F*, development of method of *E*; *G*, a single tube intricately coiled or a convoluted tubular gland.

of a muscle. The usual arrangement is for the cells to cover the free surface of a basement membrane, a dense network of capillaries to be spread upon its under surface, and nerve fibrils to form a network in contact with the cells. In order to economize space and to provide a more extensive secreting surface, the membrane is generally increased by dipping down and forming variously shaped recesses. (See Fig. 173.) If classified according to structure, glands are of two kinds:—

1. Simple.
2. Compound.

The **simple** glands are generally tubular or saccular cavities, which open upon the surface by a single duct. Sometimes the tube is so long that it coils upon itself, as in the sweat glands of the skin. The cavities from which the duct leads may vary in shape, but the secretory cells surround the cavity, and pour their secretion into it. A group of cells surrounding a tubular or saccular cavity is known as an *acinus*. A number of such acini,

when grouped together form a lobule, and a group of lobules constitutes a lobe.

In the **compound** glands the cavities are subdivided into smaller tubular or saccular cavities, opening by small ducts into the main duct, which pours the secretion upon the surface. If composed of many tubes, either straight or convoluted, they are called compound tubular glands; if composed of groups of small sacs, they are called racemose glands, because they resemble bunches of grapes. The large glands are composed of one or the other or both of these varieties.

In this group are included the glands that furnish secretions which promote digestion, *viz.*, the salivary, gastric and intestinal glands, the pancreas and liver. Also the lacrimal or tear glands; the Meibomian glands of the eyelids; the ceruminous glands of the ear; the sebaceous and sweat-glands of the skin; the mammary glands or breasts, and the kidneys.

Function of external secretions.—As might be inferred from the difference in the structure of the glands producing them, the functions vary. (1) Those concerned with digestion promote chemical reactions; (2) the lacrimal, Meibomian, ceruminous, sebaceous and sweat-glands moisten, lubricate and protect the surfaces upon which they are discharged; (3) the perspiration also helps in regulating body heat; (4) the secretion of the mammary glands furnishes nutritive material specially adapted to the needs of the young of the species. Perspiration, bile and urine are classed as excretions, but they are first secretions and with the exception of urine, are made use of during discharge.

Enzymes.—The digestive fluids owe their power to promote chemical reactions to enzymes. The exact composition of enzymes is not known. They are complex organic substances which act as catalyzers, *i.e.*, they vary (hasten or retard) the speed of chemical reactions, but they do not initiate them, or enter into them. They occur not only in glandular secretions, but in the protoplasm of the cells. It is thought the chemical activity of the cells is to some extent determined by the enzymes they contain. The following characteristics may be noted:—The body enzymes act best at the temperature of the body, (*optimum temperature*). They are destroyed by a high temperature and their effect is retarded wholly or in part by a low temperature. Each enzyme requires a *medium* of definite reaction either acid, alkaline, or neutral. The enzymes of saliva require an alkaline or neutral medium, while the enzymes of the gastric fluid require an acid

medium. The action of enzymes is *specific*, *i.e.*, enzymes that act upon fats do not act upon carbohydrates. In fact each one of the sugars seems to require its own special enzyme. Under proper conditions many chemical reactions may take place in opposite directions, or in other words they are *reversible*. For instance during digestion, an enzyme called lipase acts upon neutral fats changing them to fatty acids and glycerin. After absorption fatty acids and glycerin combine to form body fats and it is probable that lipase furthers this synthesis, just as it did the first change. This explains how fat may be stored in the subcutaneous tissues, and when need arises it may be changed to fatty acids and glycerin and oxidized.

Active and inactive form.—It has been demonstrated that an enzyme may exist within the cell producing it in an antecedent or *inactive* form which is designated as a *zymogen*. The zymogen may be stored in the cell in the form of granules which are converted into active enzyme at the moment of secretion, or it may be secreted in inactive form and require the coöperation of some other substance before it is capable of effecting its normal reaction. In such cases the second substance is said to activate the enzyme. It has been suggested that the inorganic substances causing activation shall be designated as *activators*, and organic substances serving the same purpose shall be named *kinases*. An example of the latter is the enterokinase which activates the trypsinogen of the pancreatic secretion.[4]

Coenzymes.—There are some cases where the action of an enzyme is helped by, or even dependent upon the presence of some other substance. A good example of this activity is furnished by the influence of bile-salts upon lipase.[5] These cases of *coactivity* are to be distinguished from activation, by the fact that the combination may be made or unmade. For example, in a mixture of bile-salts and lipase, the bile-salts may be removed by dialysis. In activation, on the contrary, the active enzyme cannot be changed back to the inactive zymogen.

THE ENDOCRIN OR DUCTLESS GLANDS

The endocrin or ductless glands form a group of organs that produce secretions, called internal secretions, which leave the gland by the blood or lymph. Many of the glands that possess ducts and form an external secretion form an internal secretion as well, *i.e.*, the liver and pancreas, but these are not classed as ductless, because the external secretion is carried out of the

[4] See page 380. [5] See page 383.

gland by means of a duct, though the internal secretion passes into the blood or lymph just as in the ductless glands. The function of the ductless glands is intimately connected with the purpose of the internal secretions, and this is imperfectly understood. Because it is difficult to secure internal secretion in a state of purity, *i.e.*, without the lymph or blood into which it is poured, the methods of investigation have been: (1) observation of the conditions caused by diseases of these glands; (2) various experiments on animals such as removing a gland and later transplanting a similar gland taken from another animal, or else injecting into the animal extracts prepared from the gland; (3) chemical examination of the gland, or of its extracts, or of the blood which leaves it. In some cases removal of the gland is followed by disease and death indicating that the internal secretion produced is essential for life.

Autacoids.—As a result of various investigations it has been determined that internal secretions contain substances which activate or depress the function they effect. These substances are called autacoids from two Greek words meaning *natural remedy*. The term is applied to any drug-like principle which is produced in the internal secreting tissues and organs. Those which activate functions are called *hormones*,[6] and those which depress functions are called *chalones*.[7] But it must not be understood that hormones are found only in the internal secretions, because any chemical substance which is produced in an organ and on being carried by the blood to another organ or part stimulates activity, is a hormone. The carbon dioxide formed in the tissues (particularly the muscles) acts as a hormone by stimulating the respiratory center in the medulla; and urea, the end-product of protein digestion, stimulates the kidneys.

The most important ductless glands are:—

1. The Thyroid.
2. The Parathyroids.
3. The Thymus.
4. The Suprarenal Glands or Adrenals.
5. The Pituitary body or Hypophysis.
6. The Pineal body or Epiphysis.
7. The Gonads (ovaries and testes).

Special cells in the pancreas and liver, also portions of the lining membrane of the stomach and intestines function as ductless glands, and furnish an internal secretion.

(1) **The thyroid.**—The thyroid is a small, flat gland lying against the fore part of the trachea, below the thyroid cartilage. It is a highly vascular organ, weighs about an ounce (30 gms.),

[6] From a Greek work meaning *to excite.*
[7] From a Greek word meaning *to make slack.*

and consists of a right and left lobe placed on each side of the trachea. The lower parts are broader, and are connected by a strand of their own substance called the isthmus, which stretches across the front of the trachea. The glandular portion is enveloped by areolar tissue, which extends inward, dividing the substance into lobes and lobules, and gives off folds which bind the gland in place. Small masses of thyroid tissue are sometimes found along the trachea as far down as the heart. They are

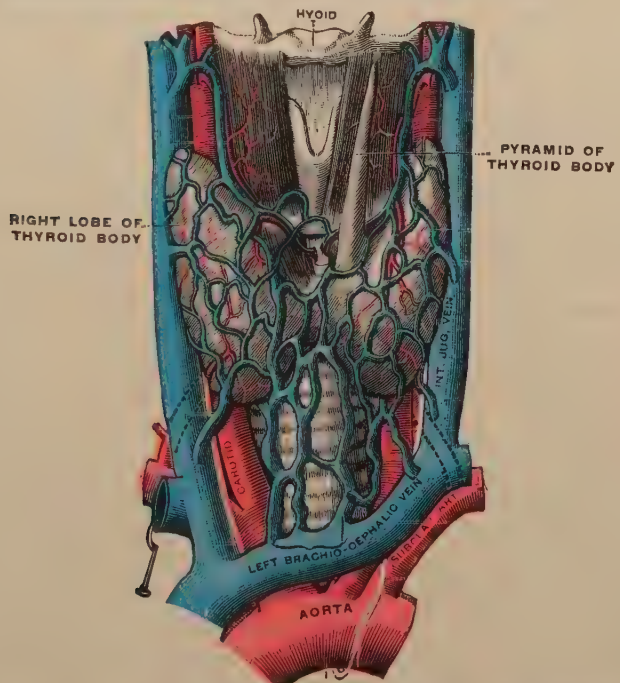


FIG. 174.—THE THYROID BODY AND THE RELATED BLOOD-VESSELS. (Gerrish.)

called **accessory thyroids.** The size of the thyroid varies with age, sex, and general nutrition, being relatively larger in youth, in women, and in the well-nourished. It increases in size temporarily during menstruation and pregnancy. Removal or disease of the thyroid resulting in an absence, decrease or increase of the internal secretion is followed by grave disturbances which are grouped under two headings, *i.e.*, hypothyroidism, or lack of thyroid secretion, and hyperthyroidism, or excess of thyroid secretion.

Hypothyroidism.—In man three pathological conditions are due to hypothyroidism, *i.e.*, goiter, cretinism and myxedema.

Goiter is a morbid enlargement of the gland resulting from increased functional activity, due to a decrease in the iodin content of the gland. This in turn is thought to be due to a decrease or lack of iodin in water and food. Good results have been obtained by the administration of small amounts of iodids, or by the use of table salt containing iodin. Goiter is endemic in the region of the great lakes in this country. Dosing of children twice a year with iodids has greatly checked the prevalence of hypothyroid goiter in the cities of Ohio, where the incidence of this condition is high.

Cretinism is a species of idiocy due to congenital defects of the thyroid, or atrophy occurring in early life. The growth of the skeleton ceases, though the bones may become thicker than normal and there is complete arrest of mental development. Children so afflicted are called cretins. They are not only dwarfed, but ill-proportioned and ugly, having heavy heads and abdomens and weak muscles. When the thyroid atrophies or is removed in adult life, the condition which results is called *myxedema*.[8] The most marked symptoms of this condition are slowness both of body and mind, usually associated with tremors and twitchings. The skin becomes rough and dry, due to lack of cutaneous secretions, and assumes a yellow, wax-like appearance. There is an overgrowth of the subcutaneous tissues, which in time is replaced by fat; the hair grows coarse and falls out; the face and hands are swollen and puffy; the body and mind are unwieldy and clumsy. Cretinism and myxedema are both due to lack of the internal secretion of the thyroid, which may be supplied by feeding on the thyroid of other animals. This treatment must be kept up for years. Iodids are beneficial and are sometimes used instead of thyroid extract.

Hyperthyroidism.—Over-activity of the thyroid gland, *i.e.*, increase in the amount of the internal secretion, produces a condition called *Graves' disease* or *exophthalmic goiter*. It is characterized by protruding eyeballs, quickened and sometimes irregular heart action, elevated temperature, nervousness and insomnia. The appetite may be, often is, excessive, but this is accompanied by loss of weight due to increased metabolism and digestive disturbances. This condition is sometimes remedied by limiting the blood-supply to the gland, either by ligating one of

[8] *Myxedema* comes from two Greek words meaning mucous swelling. This name was given because it was thought to be due to an increased amount of mucin. Many authorities argue that the increase in mucin is due to the increase of connective tissue and has no other significance.

the carotid branches or removing part of the gland, the aim in either case being to lessen the amount of the secretion.

Function.—The marked conditions resulting from an increase or decrease of the internal secretion suggest that the thyroid contains a substance which has a stimulating effect on metabolism. This active principle or hormone has been isolated, and is a compound called *thyroxin* which contains as high as 65 per cent of iodin. In normal conditions of health it is assumed that thyroxin is formed constantly and supplied to the blood in the internal secretion. The thyroid has the power to store iodin and selects from the blood the minute quantities of this element absorbed from digested food. In most regions drinking water contains traces of iodin. Sea-food contains minute quantities. Water is an important source of iodin for a large proportion of the human race.

Measurements of basal metabolism[9] show that the internal secretion of the thyroid influences the general rate of oxidation in the body. The simplest measurement is the one in which the amount of oxygen used in respiration is measured for a definite period of time. A perfectly normal person who has fasted for fifteen hours preceding the test, and is inactive the half hour preceding, and during the test, should use a definite amount of oxygen depending on the weight, height and age. This amount has been determined and is a measure of normal basal metabolism. Cases of hyperactivity show an increase in basal metabolism of from 10 to 40%. Cases of hypoactivity show a decrease in basal metabolism, sometimes as low as 30%. Thyroid feeding produces an increase in basal metabolism, a loss of weight, and in some cases an increase in the rate and force of the heart beat, often an irregularity called tachycardia; and may cause nervous excitability and flushing.

The parathyroids.—The parathyroids consist of several pairs of brownish red bodies located near the thyroids, and along the sides of the trachea below the thyroid. They consist of masses of cells arranged in columnar fashion and well supplied with capillaries. It is probable that they produce an essential internal secretion. The most important theories regarding the nature of the function of the parathyroids are (1) they are concerned with calcium metabolism in the body. This is supported by the fact that complete removal is followed by toxic results and muscular tetany. (2) The parathyroids help to maintain the acid-base

[9] See page 407

equilibrium of the body. After removal of the parathyroids, the reaction of the blood shows a tendency to acidosis. Defective carbohydrate metabolism accompanies this and may be the cause of it. (3) The neutralization of toxic compounds normally produced in metabolism. Cases of infantile tetany are thought to be due to parathyroid insufficiency.

The thymus.—The thymus is a temporary organ, reaching its greatest size at the time of puberty, when it gradually diminishes. It consists of two lateral lobes and is located partly in the neck and partly in the thorax. The function of the thymus is obscure.

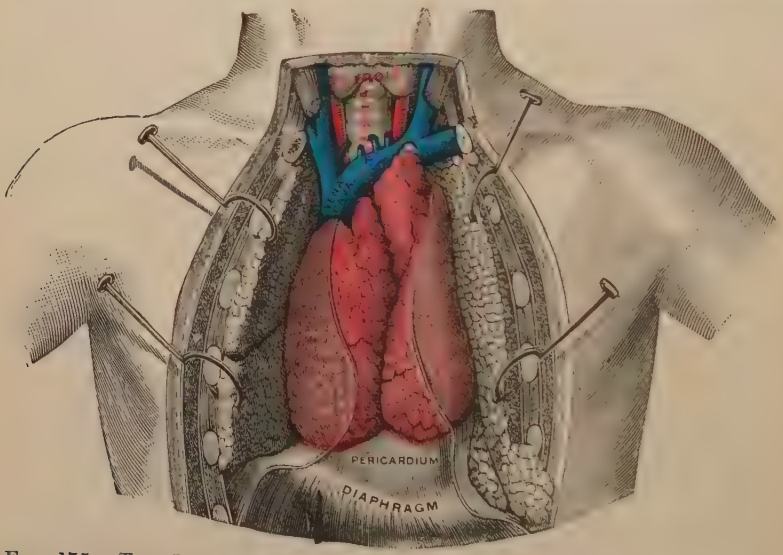


FIG. 175.—THE THYMUS, THE STERNAL AND COSTAL CARTILAGES HAVING BEEN REMOVED. (Gerrish.)

Experimental results are so contradictory that it is a question whether the thymus is a gland of internal secretion.

The suprarenal glands or adrenals.—They are small yellowish triangular-shaped bodies placed one above each kidney. (See Fig. 142.) They are surrounded by a capsule of fibrous tissue, and consist of two parts known as the cortex and the medulla, which differ in structure and function. The same group of cells in the embryo give rise to the cortex of the adrenals and the kidneys. But the medulla is derived from the same structures that give rise to the sympathetic nervous system, and is largely composed of nerve-like tissue which when treated with chromic acid stains yellow or brown, hence it is called *chromophil tissue.*

The adrenals bear the same relationship to the autonomic system, that the sympathetic ganglia do, and thus serve as a nervous structure as well as a gland. This medullary portion secretes a substance called epinephrin.[10] It is thought that under ordinary conditions only enough epinephrin is secreted to help maintain the tone of the blood-vessels, but when the adrenals are stimulated the amount of epinephrin discharged into the blood is increased, and stimulation of the sympathetic nervous system results. This effect is supposed to be due to stimulation of the myoneural connections, and the results are favorable for muscular activity, but unfavorable for digestion. Pain, fear, anger and excitement are common causes of sympathetic stimulation, and consequently of the secretion of epinephrin. The cells of the cortex differ from those of the medulla. Their function is unknown, but it is assumed that they form a secretion. There is considerable evidence indicating a connection between the cortex and the reproductive functions. Various phases of sexual life are accompanied by changes in the adrenals. It is possible that the cortical secretion is quite as important as the secretions of the medullary portion.

Removal of these bodies is followed by death. The symptoms preceding death are similar to those occurring in Addison's disease, *i.e.*, marked muscular weakness, extreme fatigue, nervous depression, great digestive irritability and pigmentation of the skin in the form of large brown spots. Addison's disease is fatal and autopsy shows lesions in the adrenals, so that it is evident these glands are essential to life.

The pituitary or hypophysis.—The pituitary is a mass of reddish gray tissue about the size of a pea. It is situated at the base of the brain, lodged in a depression in the middle portion of the sphenoid bone and firmly held in place by the dura mater.[11] It consists of an anterior and posterior lobe separated by a cleft-like space called the pars intermedia which is filled with granular cells. The anterior lobe is larger and distinctly glandular, the posterior lobe consists chiefly of neuroglia. From the results of various experiments it is evident that the hypophysis is essential to normal metabolism, and moreover that the anterior and posterior lobes exercise different functions.

The posterior lobe.—A substance called pituitrin or hypophysin is obtained from extracts of the posterior lobe. Intravenous

[10] Called also adrenalin, adrenin, and suprarenin.

[11] For description of dura mater, see page 155.

injections of such extracts produce contraction of all the plain muscle tissue of the body, shown by (1) a rise of blood-pressure, due to constriction of the peripheral arterioles and a consequent slowing and strengthening of the pulse. This is called the *pressor* effect. The opposite or *depressor* effect may follow a second injection. (2) Increased intestinal peristalsis, hence frequent medicinal use to stimulate bowel movements. (3) Contraction of the bladder and the pregnant uterus, hence medicinal use to stimulate uterine contractions. (4) Increased flow of some of the secretions, particularly the milk in nursing mothers, which is thought to be due to more complete emptying of the breasts, rather than an increase in the amount secreted. (5) Dilatation of the blood-vessels of the kidneys accompanied by pronounced diuresis. This diuretic action is transitory and is followed by a lessened secretion of urine. The disease called diabetes insipidus characterized by excretions of abnormally large amounts of urine is thought to be due to defective action of the pituitary. It has been successfully treated by the administration of pituitary extract which decreases the output of urine. Because of these results it is assumed that the function of the posterior lobe is to help maintain the tone of plain muscular tissue, and to influence the activity of the kidneys.

The anterior lobe.—There is some evidence that the anterior lobe produces a secretion which has an effect upon growth and metabolism. The injection or feeding of extracts prepared from the anterior lobe seems to cause more rapid growth and greater sexual development of dogs. It is claimed that certain abnormalities in the growth of the skeleton are related to an enlargement and presumably a hypersecretion of this lobe. If this occurs in the young, the long bones grow to an unusual length, causing an increased height, a condition known as *gigantism*. If this occurs in later life the condition known as *acromegaly* develops. The symptoms of acromegaly are enlargement of the bones, increased production of connective tissue, and consequent distortion of the face; the mandible is especially enlarged, the eyelids thicken, the lips swell; the hands and feet grow abnormally large. There is loss of intelligence, blindness is not uncommon, and may be due to pressure of the enlarged gland upon the brain. The records of cases of injury to the pituitary, and of tumors on or near the pituitary which might be expected to cause hyposecretion, show that defective or incomplete growth, persistent sexual infantilism and marked obesity are associated with such con-

ditions. Dwarfs have been known to have small pituitary glands.

It is considered probable that there is a physiological interrelationship between the anterior lobe of the pituitary, the thyroid, and the cortex of the adrenals.

The pineal body or epiphysis.—The pineal body is a small reddish gray body about 8 mm. in length, that develops as an outgrowth of the third ventricle of the brain and remains attached to the roof of the ventricle. In early life it is glandular and attains its maximum growth about the seventh year. After this period, and particularly after puberty, it decreases in size, and the glandular tissue is replaced by fibrous tissue. Its function is not known, but it is thought that it furnishes a secretion that inhibits growth and the development of the reproductive organs, however the evidence in support of this is not conclusive.

The liver.—In addition to other functions the liver forms two substances, *i.e.*, glycogen and urea from materials which it takes from the blood and which are subsequently returned to the blood. The glucose brought to the liver by the portal blood is stored in the liver cells in the form of glycogen (animal starch) and when needed is again converted to glucose. The chief end-product of the metabolism of protein food, *i.e.*, urea is eliminated by the kidneys. There is much evidence that urea is formed in the liver. The precursor of urea is ammonium carbonate which the liver cells convert into urea. These processes are examples of internal secretions.

The pancreas.—The pancreas forms an external secretion, the pancreatic fluid which is described on page 380, but special groups of cells in the pancreas called the islands of Langerhans furnish an internal secretion which changes the glucose of the blood into a form that the tissue cells are able to use. Glucose which has not been acted upon in this way, cannot be oxidized, and consequently remains in the blood until eliminated by the kidneys. This metabolic derangement is the fundamental cause of diabetes mellitus, and follows the destruction of the islands of Langerhans. The hormone secreted by the cells of the islands is called *insulin*, and due to the work of Banting and his co-workers (1921) this substance can be isolated from the normal pancreas of an animal, and used for the relief of the symptoms of diabetes. The amount of sugar in the blood, and the amount in the urine are promptly reduced by insulin. Over-doses may lower the blood-sugar to such an extent that coma develops. The premonitory symptoms are flushing of the face, sweating, general

discomfort and dizziness. These may be relieved by eating sugar; sweet chocolate is commonly used. Insulin merely supplies what is lacking in the internal secretion of the individual. It is comparable to the use of thyroid in myxedema.

Internal secretion of the gastric and intestinal mucous membrane.—The mucous membrane lining the stomach contains some cells which secrete a hormone known as gastrin. This is carried by the blood to the peptic and pyloric glands which manufacture gastric fluid, and stimulates secretion. The mucous membrane of the intestine, particularly the duodenum (portion directly next to the stomach) contains cells which secrete a substance known as prosecretin, which is inactive until the medium is acid. When the acid chyme from the stomach enters the duodenum, prosecretin is liberated, changed to secretin, absorbed by the blood, and carried to the pancreas, liver and intestines, stimulating each organ to secretory activity.

Internal secretion of the gonads (ovaries and testes).—The *ovaries*, two of the female organs of generation, produce ova and in addition produce two internal secretions. Apparently one secretion is formed by the interstitial cells in the body of the ovary, and the other by a group of cells known as the corpus luteum.[12] There is evidence to support the theory that the secretion furnished by the interstitial cells of the ovary stimulates the development of sexual characteristics in the female, as well as influencing the growth and nutritive condition of the uterus, and aids metabolism. The secretion of the corpus luteum affects if it does not control menstruation and the periodic changes involved in the menstrual cycle. It also sensitizes the mucous membrane of the uterus so that it responds to the contact of the developing ovum, and assists in the process of implantation. Further the growth of the mammary glands during pregnancy, the production of milk and the termination of pregnancy are probably connected with the growth and involution of the corpus luteum. The *testes*, two of the male organs of generation, produce spermatozoa, and furnish an internal secretion which influences the development of sex characteristics in the male,[13] aids metabolism and probably increases muscular strength and resistance to fatigue. The tendency of both sexes to become obese after castration is evidence that the sex glands stimulate metabolic processes.

Endocrin balance.—The study of the internal secretions has made it evident that the effect of certain secretions is to reinforce

[12] More fully discussed in Chapter XXIII, page 506.
[13] See page 501.

each other, and to some extent they are able to substitute for each other. Examples are the thyroid and the pituitary which stimulate metabolism. Some of the cells of the gonads might also be classed with the pituitary and the thyroid because they also stimulate metabolism. Instead of reinforcing each other, certain secretions act in directly opposite ways, *e.g.*, the pancreatic hormone favors the formation of glycogen, and epinephrin favors its change into simple sugar. This has led to much discussion regarding the classification of endocrins and the so-called endocrin balance. The idea of endocrin balance is correct if it is meant to indicate that each ductless gland has an optimum rate of activity which varies in accordance with the requirements of the body; but is incorrect if it is meant to indicate that most of the endocrins are antagonistic and are balanced against each other.

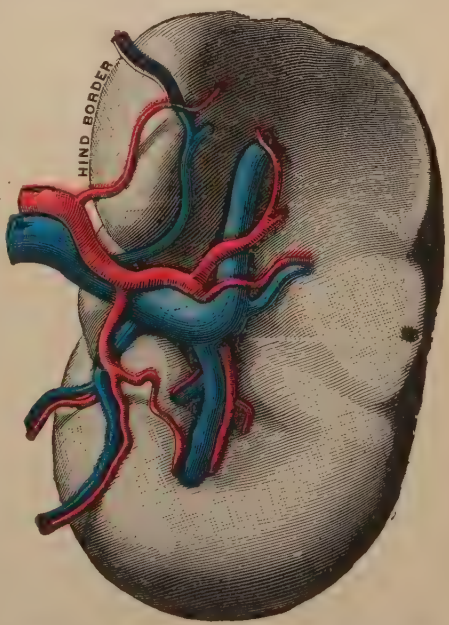


FIG. 176.—THE SPLEEN, SHOWING THE GASTRIC AND RENAL SURFACES AND THE BLOOD-VESSELS. *A*, splenic artery. *B*, splenic vein. (Gerrish.)

The spleen (lien).—Some authorities class this organ with the ductless glands and others class it with the lymph-nodes. It is situated directly beneath the diaphragm, behind and to the left of the stomach, and is covered by peritoneum from which folds extend to the diaphragm, stomach, and left kidney, and help to hold the organ in place. It is bean-shaped, convex on the outer surface and concave on the inner. Beneath the serous coat it is covered by a fibrous and elastic capsule which sends fibrous bands (trabeculæ) to form a network in the interior of the organ. The meshes of this fibrous framework are filled with a substance called spleen pulp, which is of a dark reddish brown color. The meshes of the pulp are filled with blood containing red and white cells, also large rounded cells called splenic cells which are

capable of ameboid movement, and often contain pigment and red blood cells in their interior.

Blood-supply.—Blood is supplied to the spleen by the splenic (lienal) artery, a branch of the celiac artery of the abdominal aorta. It enters the concave side of the spleen at a depression called the hilus. The arrangement of the blood-vessels is peculiar to this organ. The splenic artery divides into several branches before entering the organ, and after entering rapidly divides into smaller vessels. When the minute arteriole stage is reached, the vessels terminate, and the blood escapes into the spleen pulp. The blood is collected from the pulp by thin-walled veins, which unite to form the splenic vein. The splenic vein unites with the superior mesenteric to form the portal tube and carries the blood to the liver.

Functions.—All attempts to show indispensable or important functions the spleen have been unsuccessful. It may be removed from the body without serious injury to the animal. It is usually credited with the following:—

(1) The formation of red cells during fetal life and even after birth. It may even assume this function after severe anemia in the adult.

(2) Large numbers of erythrocytes in various stages of disintegration are found in the spleen pulp, hence it is thought to help in the disintegration of red cells.

(3) The presence of a large amount of organic iron is taken to indicate that the spleen may play a part in the preparation of new hemoglobin, or the preservation of the iron set free in the disintegration of red cells.

(4) Various waste products that result from the metabolism of nucleoproteins[14] are found in the liver and it is thought that the spleen changes these substances to uric acid which is excreted in the urine.

The most important facts known about the spleen are the slow expansion and contraction of the organ occuring during digestion. After a meal the spleen increases in size and reaches a maximum about the fifth hour of digestion. Then it slowly decreases to its former size. The significance of this is not known.

[14] See pages 405 and 413.

SUMMARY

Control of Body
1. Impulses from nerve cells—Nervous System.
2. Impulses from substances circulating in blood—Glandular System.

Glands

- **Definition**—Glands are organs that form secretions.
- **Function depends on**
  1. Chemical and physical factors—osmosis—dialysis—permeability of membranes.
  2. All the energy changes within the cells.
- **Product**
  - Secretions are substances elaborated from the blood by individual cells, or groups of cells called glands. They are intended to perform some office in the body.
    1. External—are carried to blood by ducts.
    2. Internal or endocrins—are discharged into blood or lymph.
  - Excretions—are secretions which are to be eliminated.
- **Classification based on function**
  - Secretory—form secretions
    1. Have ducts.
    2. Ductless or endocrin organs.
  - Excretory—form excretions—have ducts.

Glands with Ducts

- **Size and Structure**
  - Essentials
    1. Epithelial cells.
    2. Liberal blood-supply.
    3. Under control of Nervous System. Secretion is their response to stimulation.
  - Simple—tubular or saccular cavities—acini—open by one single duct.
  - Compound—many tubular or saccular cavities opening by small ducts into main duct.
- Salivary glands, Gastric glands, Intestinal glands, The Pancreas, The Liver—furnish secretions which promote digestion.
- Lacrimal or tear-glands, Meibomian glands of eyelids, Ceruminous glands of the ear, Sebaceous and sweat-glands of skin—Moisten, lubricate and protect surfaces on which discharged.
- Mammary glands—milk for young of species.
- The kidneys—eliminate waste.
- **Enzymes**
  - Substances produced by living cells which act by catalysis.
  - Efficacy destroyed by boiling.
  - Act best at body temperature.
  - Action is specific.
  - Action is reversible.
  - Require medium of definite reaction.
  - Antecedent or inactive form called *zymogen*, activated by
    - Activators—inorganic.
    - Kinases—organic.
  - Substances which help or act with an enzyme called *co-enzymes*.

TABLE OF SECRETIONS AND EXCRETIONS

SECRETION	SECRETING ORGANS	REACTION	MAIN PURPOSE
Mucin	Mucous cells of mucous membrane	Alkaline	Lubricant and diluent.
Serum	Serous membranes	Alkaline	Lubricant and diluent.
Tears	Lacrimal glands	Alkaline	To moisten the conjunctiva.
Saliva	Salivary glands	Alkaline	To moisten food and begin the digestion of starch.
Gastric fluid	Stomach	Acid	To begin the digestion of proteins.
Pancreatic fluid	Pancreas	Alkaline	To digest proteins, fats, and carbohydrates.
Succus entericus	Intestines	Alkaline	To stimulate the secretion of pancreatic fluid, also digest proteins, fats, and carbohydrates.
Bile	Liver	Alkaline	Part of the bile is used in digestion and reabsorbed. Part is a true excretion (bile-pigments).
Milk	Mammary glands	Alkaline	Food.
Sebum	Sebaceous glands of the skin	Alkaline	To lubricate the skin.
Sweat	Sweat-glands of skin	Alkaline	Helps to regulate body temperature. Eliminates water and a small amount of carbon dioxide.
Vaginal	Vagina	Acid	Lubricant, moistens and protects.
Urine	Kidneys	Acid	Eliminates water and urea.

Ductless Glands

- Glandular structures that possess no ducts.
- Produce internal secretions that are carried from the gland by the blood or lymph.
- Function is imperfectly understood — Methods of investigation:
  - Observation of conditions caused by disease.
  - Experiments on animals.
  - Chemical examination of gland and of blood that leaves it.
- The Thyroid.
- The Parathyroids.
- The Thymus.
- The Suprarenal glands or adrenals.
- The Pituitary or Hypophysis.
- The Pineal body or Epiphysis.
- Gonads:
  - The Testes—male.
  - The Ovaries—female.
- Autacoids — drug-like principles produced in internal secreting tissues and organs:
  - Hormones[15]—stimulate activity.
  - Chalones—inhibit or depress activity.

[15] It must be remembered that the term hormone is applied to any chemical substance which is produced in a reaction and on being carried by the blood to another organ or part stimulates activity. Consequently the use of the term is not limited to substances produced by glands.

Thyroid

- Small gland. Weighs about one ounce.
- Consists of two lobes connected by an isthmus.
- Placed in front of trachea, below thyroid cartilage.
- Function is secretion of a hormone—thyroxin—that stimulates metabolism.
- **Hypothyroidism or lack of thyroid secretion**
  - Goiter—morbid enlargement.
  - Cretinism—species of idiocy, due to congential defect of thyroid or atrophy in early life.
  - Myxedema—due to atrophy of thyroid in adult life.
- **Hyperthyroidism or excess of thyroid secretion**
  - Graves' disease or exophthalmic goiter.

Parathyroids

- Several pairs of brownish-red bodies located near the thyroids and along the sides of the trachea.
- Consist of masses of cells well supplied with capillaries.
- **Function**
  - Concerned with calcium metabolism.
  - Help to maintain acid-base equilibrium.
  - Neutralization of toxic compounds.

Thymus

- Temporary organ.
- Reaches greatest size at puberty.
- Function not definitely determined.

Suprarenal bodies of adrenals

- Triangular-shaped bodies, placed one above each kidney.
- Surrounded by fibrous network and consist of two parts
  - Cortex—function unknown. Assumed that it forms an internal secretion.
  - Medulla—vascular mass of nerve-like tissue secretes epinephrin.
- **Function**
  - Small amount of epinephrin helps maintain tone of the blood-vessels.
  - Large amount of epinephrin stimulates sympathetic nervous system.
  - Evidence of a connection between the cortex and reproductive functions.
  - Removal of these bodies causes death. Symptoms preceding death similar to Addison's disease.

Pituitary or Hypophysis

- Small mass of reddish gray tissue, size of pea, situated at base of brain, lodged in depression of sphenoid bone.
- **Consists of three portions**
  1. Anterior lobe, glandular. Pars Intermedia, cleft-like space between two lobes, filled with secreting cells.
  2. Posterior lobe, consists of neuroglia.
- **Function**
  - Anterior lobe. Thought to influence growth of skeleton, possibly all connective tissues.
  - Posterior lobe—extract is pituitrin or hypophysin. Thought to help maintain tone of plain muscular tissue, and influence activity of kidneys.

Pineal Body or Epiphysis

- Small reddish gray body develops as an outgrowth of the third ventricle of the brain. Glandular organ; attains maximum growth about seventh year. From this period and particularly after puberty it decreases in size and becomes fibrous.
- Function not definitely known; it is thought that it furnishes a secretion that inhibits growth and development of the reproductive organs.

Liver

- It is assumed that the liver regulates the chemical changes on which the conversion of glucose into glycogen, and glycogen into glucose depends. The liver forms urea, which is eliminated by the kidneys.

Pancreas
- Islands of Langerhans furnish a hormone called *insulin*.
- Insulin reduces amount of sugar in the blood and amount excreted in the urine.

Gastric and Intestinal Mucous Membrane
- Some of the cells of the lining of the stomach secrete a hormone called gastrin—stimulates secretion of peptic and pyloric glands.
- Some of the cells of the lining of the intestine form prosecretin, which changes to secretin when the medium is acid. Secretin stimulates secretory activity of pancreas, liver and intestines.

Gonads

Ovaries
- Two of the female organs of generation.
- **Furnish**
  - Ova—cells from which new beings may develop.
  - Two secretions which stimulate development of sexual characteristics, aid metabolism, and affect menstrual cycle.

Testes
- Two of the male organs of generation.
- **Furnish**
  - Spermatozoa—one of which may unite with one of the ova to produce a new being.
  - Internal secretion—influences development of sex characteristics in male, and aids metabolism.

Endocrin balance
- Indicates that each ductless gland has an optimum rate of activity which varies in accordance with the requirements of the body.

Spleen

Description
- Beneath diaphragm, behind and to the left of the stomach.
- Consists of a fibrous network filled with a vascular pulp, enclosed in a fibrous and muscular capsule which is covered by serous membrane.
- Blood supply peculiar—arteries—veins, no connecting capillaries.

Functions
- Not definitely known. Credited with the following:—
1. Formation of red cells during fetal life and after birth if need arises.
2. Helps in disintegration of red cells.
3. May play a part in preparation of hemoglobin, or preservation of iron.
4. Changes waste products of nucleoproteins to uric acid, which the kidneys can excrete.

CHAPTER XVI

RESPIRATORY SYSTEM: NOSE; LARYNX; TRACHEA; BRONCHI; LUNGS.—RESPIRATION; RESPIRATORY PHENOMENA.

All living things require oxygen for their vital processes. The normal course of all the chemical changes in the tissue cells is dependent upon oxygen, hence the need of a continual supply. One of the end-products of the same chemical changes is carbon dioxide, hence the need for continual elimination. In unicellular animals the intake of oxygen and the output of carbon dioxide occur at the surface of the cell. As organisms increase in size some form of apparatus is developed whose function consists in bringing air or oxygen-laden water to all the cells of even the most complex organism. In man the circulating blood is brought in contact with the air in the lungs, where it takes up oxygen and gives up carbon dioxide, and later with the cells in the tissues where it gives up oxygen and takes up carbon dioxide.

This exchange of gases is known as respiration and is dependent upon the proper functioning of certain organs which we group together and call a *respiratory system.* The essentials of a respiratory system consist of a moist and permeable membrane, with

FIG. 177.—DIAGRAM OF THE ESSENTIALS OF A RESPIRATORY SYSTEM. (Gerrish.)

a moving stream of blood containing a high percentage of carbon dioxide on one side, and air or fluid containing a high percentage of oxygen on the other. In most aquatic animals the respiratory organs are external in the form of gills; in terrestrial, or air-breathing animals, the respiratory organs are situated internally in the form of lungs, and are placed in communication with the nose and mouth by means of the bronchi, trachea, and larynx.

NOSE

The nose is the special organ of the sense of smell, but it also serves as a passageway for air going to and from the lungs. It filters, warms, and moistens the entering air, and also helps in

phonation. It consists of two parts,—the external feature, the nose, and the internal cavities, the nasal fossæ.

The external nose is composed of a triangular framework of bone and cartilage, covered by skin and lined by mucous membrane. On its under surface are two oval-shaped openings—the nostrils, which are the external openings of the nasal cavities. The margins of the nostrils are usually provided with a number of hairs.

The nasal cavities are two wedge-shaped cavities, separated from one another by a partition, or septum. The upper and back parts of the septum are formed by the perpendicular plate of the

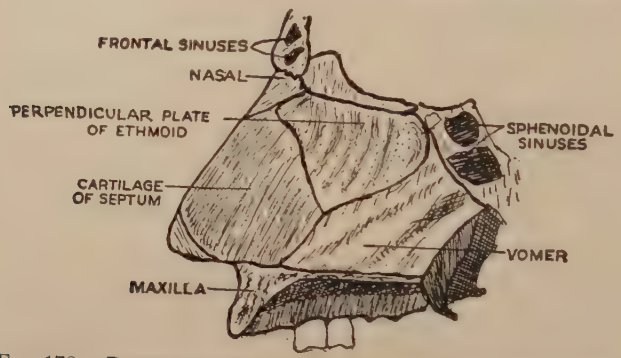


Fig. 178.—Bones and Cartilage Forming Septum of Nose.

ethmoid and the vomer, and the lower front part is formed by cartilage. This is shown in Figure 178. The septum is nearly always bent more to one side than the other, a condition to be remembered in giving nasal treatments.

The conchæ and processes of the ethmoid, which are exceedingly light and spongy, project into the nasal cavities, and divide them into three incomplete passages from before backwards, —the superior, middle, and inferior meatus. The palate and maxillæ separate the nasal and mouth cavities, and the horizontal plate of the ethmoid forms the partition between the cranial and nasal cavities.

These cavities[1] communicate with the air in front by the anterior nares, or nostrils, while behind they open into the back of

[1] Eleven bones enter into the formation of the nasal cavities: the floor is formed by the palatine (2) and part of the maxillæ bones (2); the roof is chiefly formed by the horizontal plate of the ethmoid bone (1), the sphenoid (1), and by the (2) small nasal bones; in the outer walls we find, in addition to processes from other bones, the two conchæ (2). The vomer (1) forms part of the septum.

the pharynx by the two posterior nares. They are lined with mucous membrane which is highly vascular and covered with ciliated epithelium. In children it contains a large amount of lymphoid tissue. It is continuous externally with the skin, and internally with the mucous membrane lining the passages and sinuses shown in Fig. 119. Inflammatory conditions of the nasal mucous membrane may extend into the sinuses.

Advantage of nasal breathing.—Under normal conditions breathing should take place through the nose only (1) because the

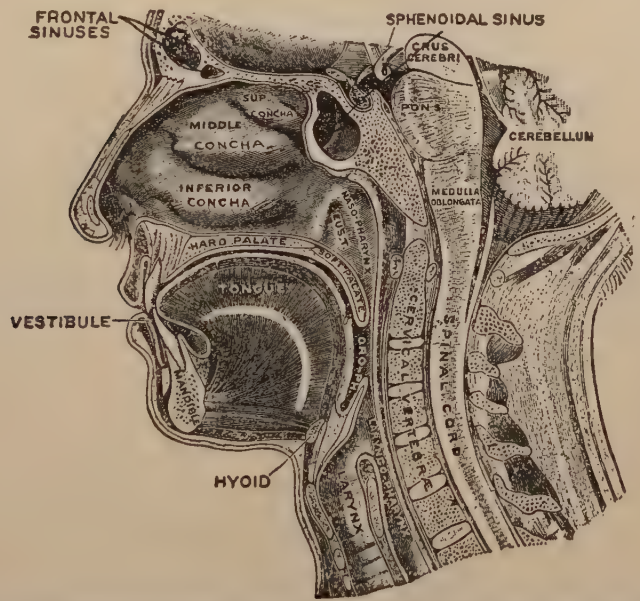


FIG. 179.—SAGITTAL SECTION OF THE FACE AND NECK, SHOWING THE FIRST PORTIONS OF THE ALIMENTARY AND RESPIRATORY TRACTS. (Gerrish.)

arrangement of the conchæ makes the upper part of the nasal passages very narrow; (2) these passages are thickly lined, and freely supplied with blood which keeps the temperature relatively high and makes it possible even in the very coldest weather to moisten and warm the air before it reaches the lungs; and (3) the presence of hairs at the entrance to the nostrils and the cilia of the epithelium, serve as filters to arrest the passage of dust or other foreign substances which might be carried in with the inspired air.

Mouth and pharynx.—The mouth serves as a passageway for the entrance of air, and the pharynx transmits the air from the

nose or mouth to the larynx, but both are closely associated with digestion and will be described with the digestive organs.

RESPIRATORY SYSTEM

Under this heading we group the organs which are concerned in the process of respiration. In man they are as follows:—

1. Larynx. 2. Trachea. 3. Bronchi. 4. Lungs.

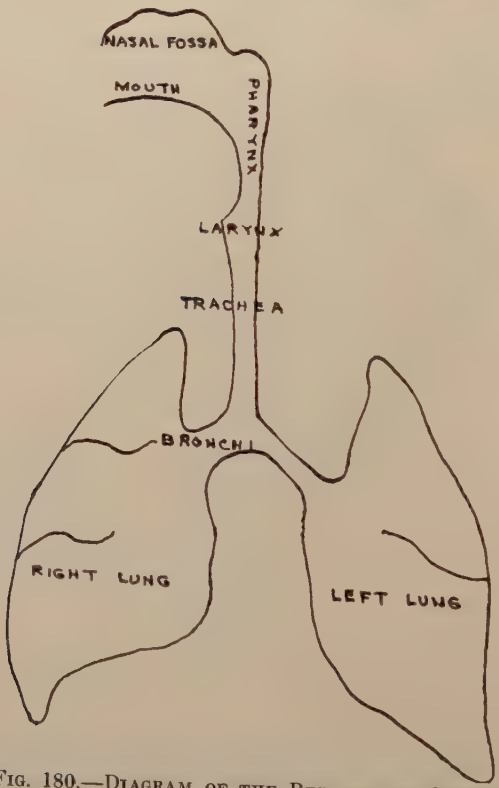


FIG. 180.—DIAGRAM OF THE RESPIRATORY SYSTEM.

THE LARYNX

The larynx, or organ of voice, is placed in the upper and front part of the neck, between the base of the tongue and the top of the trachea. Above and behind lies the pharynx, which opens into the esophagus, or gullet, and on either side of it lie the great vessels of the neck. The larynx is broad above and shaped somewhat like a triangular box, with flat sides and prominent ridge in front. Below it is narrow and rounded where it blends

with the trachea. It is made up of nine pieces of fibro-cartilage, united by elastic ligaments, and moved by numerous muscles.

The three principal cartilages are the **cricoid, thyroid,** and **epiglottis.** The cricoid resembles a seal ring with the hoop part in front and the signet part in the back. The thyroid resembles a shield and is the largest. It rests upon the cricoid and consists of two square plates, or laminæ (right and left), which are joined in front and form by their union the laryngeal prominence,

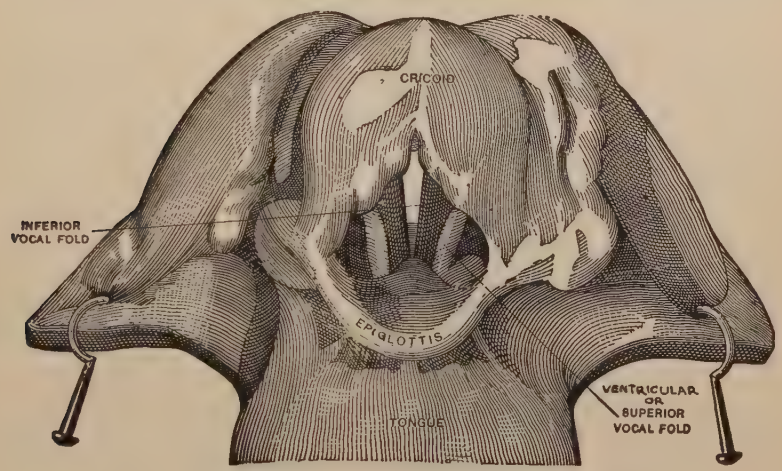


FIG. 181.—LARYNX. Viewed from above. (Gerrish.)

called Adam's apple. The epiglottis is shaped like a leaf. The stem is inserted in the notch between the two plates of the thyroid. The larynx is lined throughout by mucous membrane, which is continuous above with that lining the pharynx, and below with that lining the trachea.

The glottis.—Across the middle of the larynx is a transverse partition, formed by two folds of the lining mucous membrane, stretching from side to side, but not quite meeting in the middle line. They thus leave in the middle line a chink, or slit, running from front to back, called the *glottis*, which is the narrowest segment of the air passages. The glottis is protected by the leaf-shaped lid of fibrocartilage, called the epiglottis, which shuts down upon the opening during the passage of food or other matter into the esophagus.

The vocal folds.—Embedded in the mucous membrane at the edges of the slit are fibrous and elastic ligaments, which

strengthen the edges of the glottis and give them elasticity. These ligamentous bands, covered with mucous membrane, are firmly attached at either end to the cartilages of the larynx, and are called the inferior or *true vocal folds*, because they function in the production of the voice. Above these folds are two ventricular folds, which do not function in the production of the voice.

Variations in size of glottis.—The glottis varies in shape and size, according to the action of the muscles upon the laryngeal

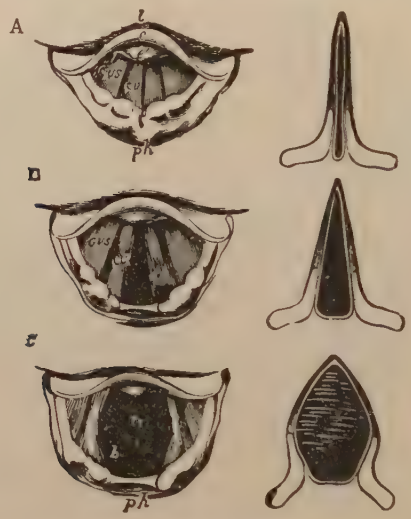


Fig. 182.—The Larynx as Seen by Means of the Laryngoscope in Different Conditions of the Glottis. *A*, while singing a high note; *B*, in quiet breathing; *C*, during a deep inspiration; *l*, base of tongue; *e*, upper free edge of epiglottis; *e'*, cushion of the epiglottis; *ph*, part of anterior wall of pharynx; *cv*, the true vocal folds; *cvs*, the false vocal folds; *tr*, the trachea.

walls. When the larynx is at rest during quiet breathing, the glottis is V-shaped; during a deep inspiration it becomes almost round, while during the production of a high note the edges of the folds approximate so closely as to leave scarcely any opening at all.

THE TRACHEA

The trachea, or windpipe, is a fibrous and muscular tube, about four and a half inches (11.2 cm.) in length, and about an inch (2 to 2.5 cm.) from side to side. It lies in front of the esophagus and extends from the larynx on the level of the sixth cervical

vertebra, to opposite the fourth or fifth thoracic vertebra where it divides into two tubes,—the two bronchi,—one for each lung.

The walls are strengthened and rendered more rigid by rings of cartilage embedded in the fibrous tissue. These rings are

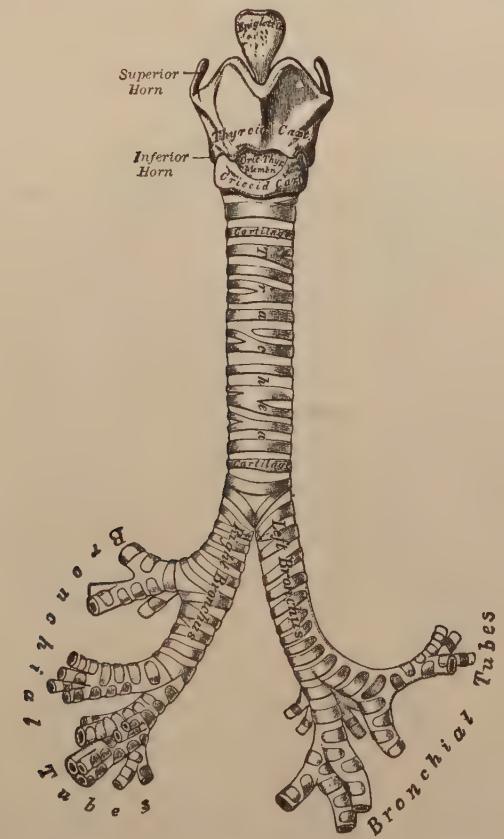


FIG. 183.—FRONT VIEW OF CARTILAGES OF LARYNX. Trachea and Bronchi.

C-shaped and incomplete behind, the cartilaginous rings being completed by bands of plain muscular tissue where the trachea comes in contact with the esophagus. Like the larynx, it is lined by mucous membrane, and has a ciliated epithelium upon its inner surface. The mucous membrane, which also extends into the bronchial tubes, keeps the internal surface of the air-passages free from impurities; the sticky mucus entangles particles of dust and other matters breathed in with the air, and

the incessant movements of the cilia continually sweep this dirt-laden mucus upward and outward.

Nerve supply of the larynx and trachea.—The larynx and trachea are supplied with fibers from the sympathetic and the cranial autonomic nerves. Stimulation of the sympathetic nerves causes relaxation of the muscular tissue and checks secretion. Stimulation of the cranial autonomic nerves contracts the muscular tissue and increases secretion.

THE BRONCHI

The two bronchi, into which the trachea divides, differ slightly; the right bronchus is shorter, wider, and more nearly vertical, the left bronchus is longer, narrower, and more nearly horizontal. They enter the right and left lung, respectively, and then break up into a great number of smaller branches which are called the bronchial tubes, or bronchioles. The two bronchi resemble the trachea in structure; but as the bronchial tubes divide and subdivide, their walls become thinner, the small plates of cartilage cease, the fibrous tissue disappears, and the finer tubes are composed of only a thin layer of muscular and elastic tissue lined by ciliated epithelium. Each bronchiole terminates in an enlargement called the atrium (infundibulum). From each atrium there is a series of small sac-like projections known as alveoli, or air cells. The walls of the alveoli consist of a thin film of elastic tissue lined internally with a single layer of flat cells.

LUNGS

The lungs are cone-shaped organs which occupy the two lateral chambers of the thoracic cavity and are separated from each other by the heart and other contents of the mediastinum. Each lung presents an outer surface which is convex, a base which is concave to fit over the convex portion of the diaphragm, and an apex which extends about an inch or an inch and one-half (2.5-4 cm.) above the level of the sternal end of the first rib. On the inner surface is a vertical notch called the **hilum,** which gives passage to the structures which form the root of the lung. Each lung is connected to the heart and trachea by the pulmonary artery, pulmonary vein, bronchial arteries and veins, the bronchus, plexuses of nerves, lymphatics, lymph-nodes and areolar tissue which are covered by the pleura, and constitute the *root* of the lung.

The **right lung** is the larger and heavier; it is broader than the

left, owing to the inclination of the heart to the left side; it is also shorter by one inch, in consequence of the diaphragm rising higher on the right side to accommodate the liver. The right lung is divided by fissures into three lobes, superior, middle, and inferior.

The **left lung** is smaller, narrower, and longer than the right. It is divided into two lobes, superior (upper) and inferior (lower). The front border is deeply notched to accommodate the heart.

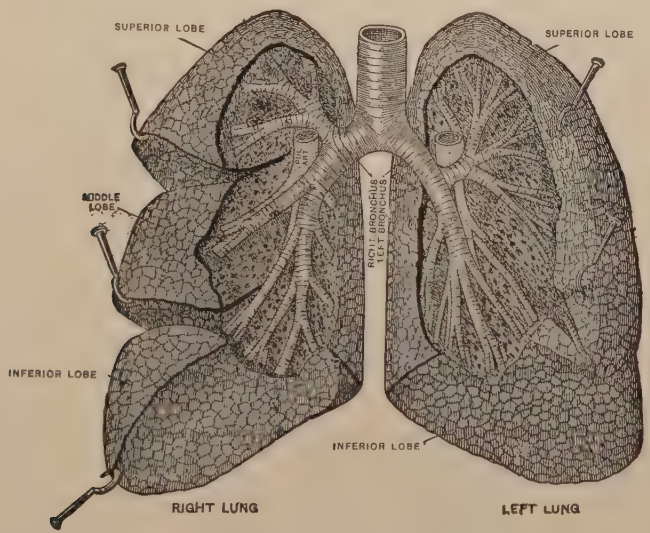


FIG. 184.—BRONCHI AND BRONCHIOLES. The lungs have been widely separated and tissue cut away to expose the air tubes. (Gerrish.)

Anatomy of the lungs.—The substance of the lungs is porous and spongy; owing to the presence of air it crepitates when handled, and floats in water. It consists of bronchial tubes and their terminal dilatations, numerous blood-vessels, lymphatics, nerves and an abundance of fine, elastic, connective tissue binding all together. (See Fig. 127.) Each lobe of the lung is composed of many lobules, and into each lobule a bronchiole enters and terminates in an atrium (infundibulum.) Each atrium presents a series of air cells or alveoli. In this way the amount of surface exposed to the air and covered by the capillaries is so immensely increased that it is estimated the entire inner surface of the lungs is one hundred times greater than the skin surface of the body.[2]

[2] It is estimated that the amount of lung surface which is exposed to the air is 90 square meters and the average skin surface is estimated to be 9/10 of one square meter.

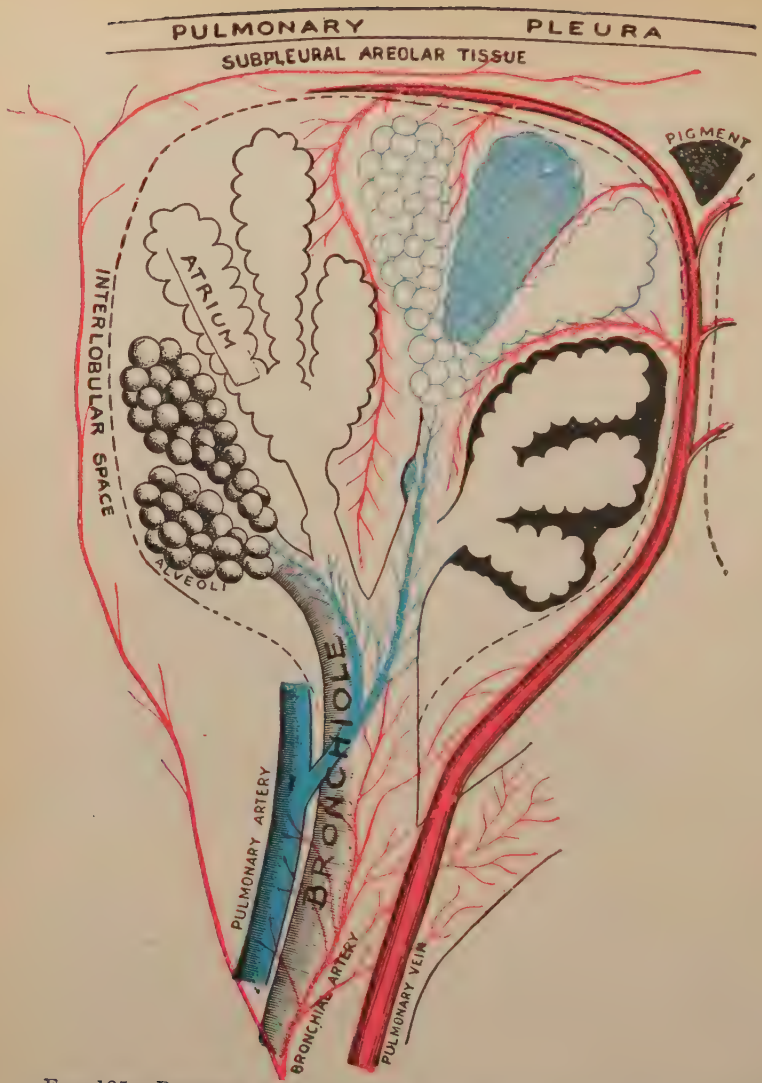


FIG. 185.—DIAGRAM OF A LOBULE OF THE LUNG. A bronchiole is seen dividing into two branches, one of which runs upward and ends in the lobule. In the lobule are four groups of atria. At the left are two atria, the alveoli or air cells of which present their outer surfaces. Next are three atria in vertical section, the alveoli of each opening into the common passageway. In the next group the first atrium shows a pulmonary arteriole surrounding the opening of each alveolus, and the second gives the same with the addition of the close capillary network in the wall of each alveolus. Around the fourth group is a deep deposit of pigment, such as occurs in old age, and in the lungs of those who inhale coal dust and the like. On the bronchiole lies a branch of the pulmonary artery (blue), bringing blood to the atria for aëration. Beginning between the atria are the radicles of the pulmonary vein (red). The bronchial artery is shown as a small vessel bringing nutrient blood to the bronchiole. (Gerrish.)

Blood-vessels of the lungs.—Two sets of vessels are distributed to the lungs: (1) the branches of the pulmonary artery, which bring blood to be aërated, and (2) the branches of the bronchial arteries, which bring blood for nutritive purposes.

(1) The branches of the pulmonary artery accompany the bronchial tubes and form a plexus of capillaries around the alveoli. The walls of the alveoli consist of a single layer of flattened epithelial cells, surrounded by a fine, elastic connective tissue, and are exceedingly thin and delicate. Immediately beneath the layer of flat cells, and lodged in the elastic connective tissue, is this very close plexus of capillaries; and the air reaching the alveoli by the bronchial tubes is separated from the blood in the capillaries only by the thin membranes forming their respective walls. The pulmonary veins begin at the margin of the alveoli and return the blood distributed by the pulmonary artery.

(2) The branches of the bronchial arteries supply blood to the lung substance,—the bronchial tubes, coats of the blood-vessels, the lymph-nodes, and the pleura. The bronchial veins return the blood distributed by the bronchial arteries.

Pleura.—Each lung is enclosed in a serous sac, the pleura, one layer of which is closely adherent to the walls of the chest and diaphragm (parietal); the other closely covers the lung (visceral or pulmonary). The two layers of the pleural sacs, moistened by serum, are normally in close contact, and the so-called pleural cavity is a potential rather than an actual cavity; they move easily upon one another, and prevent the friction that would otherwise occur between the lungs and the walls of the chest with every respiration. If the surface of the pleura becomes roughened as occurs in inflammation (pleurisy) more or less friction results and the sounds produced by this friction can be heard if the ear is applied to the chest. In health only a small amount of fluid is secreted and its absorption by the lymphatics almost keeps pace with its secretion, so that normally the amount of serum is very small. In pleurisy the amount may be considerably increased due to the extra activity of the irritated secretory cells and excessive transudation from the congested blood-vessels. The amount may be sufficient to separate the two layers of the pleura, thus changing the potential pleural cavity into an actual one. This is known as pleurisy with effusion.

Mediastinum.—The mediastinum is the space left in the median portion of the thorax between the pleural sacs. It ex-

tends from the sternum to the spinal column, and contains the heart in its pericardium, the large blood-vessels connected with the heart, part of the thoracic duct, the thymus gland or vestiges of it, the trachea, esophagus, portions of the vagus and phrenic nerves.

RESPIRATION

The main purpose of respiration is to supply all the cells of the body with oxygen and rid them of the excess carbon dioxide which results from oxidation. It also helps to equalize the temperature of the body and get rid of excess water. To accomplish these purposes three processes are necessary:—

(1) *Breathing.*—The process of breathing may be subdivided into inspiration or breathing in, and expiration or breathing out. Inspiration is a preliminary process whereby air is introduced into the lungs. Expiration is the process by which air is expelled from the lungs. This air has given up about one-fourth of its oxygen and increased the quantity of carbon dioxide one hundred times.[3]

(2) *External respiration.*—This includes two processes: (*a*) external oxygen supply or the passage of oxygen from the alveoli of the lungs to the blood; and (*b*) external carbon dioxide elimination or the passage of carbon dioxide from the blood into the alveoli of the lungs.

(3) *Internal respiration.*—This also includes two processes: (*a*) internal oxygen supply or the passage of oxygen from the blood to the cells of the tissues; and (*b*) internal carbon dioxide elimination or the passage of carbon dioxide from the cells of the tissues to the blood.

It is evident that external respiration is a process that takes place in the lungs and that internal respiration is a process that takes place in all the cells that make up the tissues of the body.

Mechanism of inspiration and expiration.—The respiratory movements consist of an alternate outward and inward movement of the walls of the thorax, which leads first to an increase and then to a decrease in the capacity of this cavity and a corresponding change in the distention of the lungs. The first movement, inspiration, is the result of the contraction of the muscles of inspiration, the second, expiration, is mainly a passive process depending to a large extent upon the elastic recoil of the parts previously put upon the stretch. The enlargement of the thoracic cavity is accomplished in three directions: (1) dorso-ventral, (2) lateral, and (3) vertical (antero-posterior). This

[3] See page 317.

is brought about by the action of the intercostal and other muscles, which elevate the ribs and thereby increase the dorso-ventral and lateral diameters. The descent of the diaphragm caused by contraction of the diaphragmatic muscles increases the vertical diameter, and pushes down the neighboring abdominal viscera. The lungs are expanded exactly in proportion as the cavity in which they lie enlarges. The pressure in the alveoli (intrapulmonic pressure) is practically *constant*, because they communicate with the outside by means of non-collapsible tubes. The pressure in the closed thoracic cavity (intrathoracic pressure) is *variable* depending on the increase and decrease in the size of the cavity. After the chest has been enlarged by the elevation of the ribs and the lowering of the diaphragm, the intrathoracic pressure in the thoracic cavity becomes *diminished*. Then the pressure of air against the alveoli from the outside is less than the pressure against the alveoli from the inside. Hence the elastic alveoli are pushed out or stretched until the pressure against them from both sides is the same.[4] The relaxation of the inspiratory muscles, the elasticity of the lungs, and the weight and elasticity of the chest walls, cause the chest to return to its original size, in consequence of which the air is expelled from the lungs. As in the heart, the auricular systole, the ventricular systole, and then a pause, follow in regular order; so in the lungs the inspiration, the expiration, and then a pause, succeed one another.

Muscles of inspiration.—The number of muscles used in breathing varies greatly, depending on whether it is quiet or labored. Usually the diaphragm and all the muscles attached to the thorax whose contraction causes an elevation of the ribs are classed as inspiratory muscles. This includes the following: (1) the levatores costarum, (2) the external intercostals, (3) the scaleni,[5] (4) the sternocleidomastoid, (5) the pectoralis minor, and (6) the serratus posticus superior.[6] In forced inspirations the action of these muscles is supplemented by additional muscles of the trunk, larynx, pharynx, and face.

[4] If a puncture is made through the chest walls so that air enters between the two layers of the pleura (pneumothorax) the lung will collapse. If the puncture is closed the air will be gradually absorbed and the lung will resume its normal position.

[5] Singular *scalenus*. There are three, scalenus anterior, scalenus medius, and scalenus posterior. They arise from the transverse processes of the cervical vertebræ, and are inserted in the first and second ribs.

[6] The serratus posticus superior extends from the spinous processes of the seventh cervical and upper two or three thoracic vertebræ to the upper borders of the second, third, fourth, and fifth ribs.

Muscles of expiration.—Normal respiration is considered a passive act due to gravity and the elastic recoil of the lungs. But in forced expirations diminution in the size of the thorax may be accomplished in two ways: (1) by forcing the diaphragm farther up into the thoracic cavity, a result obtained *not* by direct action of the diaphragm, but by contracting the muscular walls of the abdomen, the external and internal oblique, the rectus and the transversalis; and (2) by depressing the ribs. The muscles which exert this action are as follows: (1) internal intercostals, and (2) the transversus thoracis.[7] Some authorities add the (1) iliocostalis,[8] (2) serratus posticus inferior,[9] and (3) the quadratus lumborum, as the anatomical attachments of these muscles would enable them to depress the ribs.

Types of respiration.—Two distinctive types of respiration are noted. In the costal type the upper ribs move first and their elevation is the noticeable factor. In the abdominal type the expansion of the thoracic walls and lungs is greater, and the resultant respiration is deeper. The abdomen bulges outward first and this is followed by a movement of the thorax.

Respiratory center.—Unlike the beat of the heart the contractions of the respiratory muscles are entirely dependent on the nervous system, especially that part known as the *respiratory center*, which is located in the medulla oblongata. Some authorities call attention to the fact that normal respiration consists of an active inspiration and a passive expiration. Because the stimulation from the respiratory center produces the coördinated activity of the inspiratory muscles, it is suggested that this center might be designated the inspiratory center. The question arises, is there an expiratory center? There is no definite experimental knowledge on which to base the answer, but the existence of such a center is assumed. Efferent nerves from the respiratory center travel down the spinal cord and end at different levels, where they connect with the fibers of the vagi and sympathetic nerves that are distributed in the lung tissue. Afferent nerves lead from these different levels to the respiratory center.

The consensus of opinion at the present time seems to be that

[7] Transversus thoracis or triangularis sterni is found on the front and inner side of the thoracic wall. Its fibers pass from the sternum running upward and outward to be inserted in the costal cartilages from the second to the sixth rib.

[8] The iliocostalis is one of the divisions of the sacrospinalis and is inserted into the inferior borders of the lower six or seven ribs.

[9] The serratus posticus inferior arises from the spinous processes of the lower two thoracic and upper second or third lumbar vertebra, and the insertion is in the inferior borders of the lower four ribs.

the action of the respiratory center is automatic, *i.e.*, it is constantly sending impulses in a rhythmic manner over the efferent fibers leading from it, but that the rate of the respiratory movements is controlled (1) by the vagi nerves, and (2) by the chemical condition of the blood.

(1) The vagus nerve embraces two kinds of afferent fibers, or rather, afferent fibers which are capable of conducting two types of impulses. One of these inhibits inspiration, and the other inhibits expiration. The inhibition of the inspiratory muscles allows the development of the expiratory process, while the inhibition of the expiratory muscles favors the occurrence of inspiration.

(2) The respiratory center shows a specific irritability for carbon dioxide and an increased amount of carbon dioxide in the blood acts as a stimulus, increasing the rate and depth of the respirations, so that the lungs are more thoroughly ventilated. An increased amount of carbon dioxide is usually associated with a lack of sufficient oxygen, and for many years there was much difference of opinion as to which of these two conditions was the more effective stimulant of the respiratory center. It has been demonstrated that carbon dioxide is the more important, nevertheless the respiratory center and the rest of the nervous system are very sensitive to a diminished oxygen supply. Ordinarily the need for extra oxygen in the body is brought about by muscular activity, for this increases the rate of oxidation, and causes a proportionate increase of carbon dioxide. Consequently the blood distributed to the respiratory center contains a higher percentage than usual. This stimulates the center with the result that the rate and depth of the respirations are increased, thus increasing the intake and output of air, and consequently increasing the oxygen content of the blood and decreasing the carbon dioxide content. The oxygen content of the blood will be reduced by anything that (1) impedes the circulation through the lungs, (2) decreases the number of red cells in the blood, (3) interferes with the passage of air to the lungs, or reduces the amount of oxygen in the alveoli. When there is no obstruction to the entrance of air the most common cause of extreme reduction of air in the alveoli is the low atmospheric pressure existing at high altitudes.[10]

Control of respiration.—To some extent breathing can be controlled by the will. It is possible to increase or decrease the rate of respiration within certain limits by voluntary effort for a short

[10] Air pressure at sea level is about fifteen pounds to the square inch, but the pressure at high altitudes is much lower than at sea level because the degree of pressure that gases exert depends upon their depth.

time, but this cannot be done continuously. If we intentionally arrest the breathing or diminish its frequency, the nervous impulse soon becomes too strong to be controlled, and the movements will be resumed as usual. This is due to an increased amount of carbon dioxide in the blood, and consequent stimulation of the respiratory center, which makes it impossible for a person to exert further control. If, on the other hand, we purposely take a number of deep, rapid breaths, the amount of carbon dioxide in the blood is reduced, the stimulation of the respiratory center is lessened, and this results in a condition known as *physiological apnea, i.e.,* where the blood is so rich in oxygen and poor in carbon dioxide that a respiratory act is unnecessary.

Reflex stimulation of the respiratory center.—Every one must have noticed that the respiratory movements are affected by stimulation of the sensory nerves. Strong emotion, sudden pain, or a dash of cold water on the skin produces changes in the rate of the respirations. It is assumed, therefore, that the respiratory center is in connection with the sensory fibers of all the cranial and spinal nerves.

Cause of the first respiration.—The immediate cause of the first respiratory effort is closely connected with the cause of the activity of the respiratory center during life. The stimulus is supposed to come from (1) the increased amount of carbon dioxide in the blood, due to the cutting of the umbilical cord; and (2) stimulation of the sensory nerves of the skin, due to cooler air, handling, etc. During intrauterine life the fetus receives its supply of oxygen, and gives off carbon dioxide by means of the blood-vessels of the cord, which connect with the placenta. The lungs are in a collapsed condition and contain no air. The walls of the air sacs are in close contact, and the walls of the smaller bronchial tubes, or bronchioles, touch one another. When the chest expands with the first breath, the inspired air has to overcome the adhesions existing between the walls of the bronchioles and air sacs. The force of this first inspiratory effort, spent in opening out and unfolding, as it were, the inner recesses of the lungs, is considerable. In the succeeding expiration, most of the air introduced by the first inspiration remains in the lungs, succeeding breaths unfold the lungs more and more, until finally the air sacs and bronchioles are all opened up and filled with air. The lungs thus once filled with air are never completely emptied again until after death.

Frequency of respiration.—The average rate of respiration for an adult is about fourteen per minute. In health this rate may be increased by muscular exercise, emotion, etc. Anything that affects the heart beat will have a similar effect on the respirations. Age has a marked influence. The average rate during the first year of life is about forty-four per minute, and at the age of five years, twenty-six per minute. It is reduced between the ages of fifteen and twenty-five to the normal standard.

External respiration.—As previously stated this term is applied to the interchange of gases that takes place in the lungs. Once or twice each minute all the blood in the body passes through the capillaries of the lungs. This means that the time during which any portion of blood is in a position for respiratory exchange is only a second or two. Yet during this time, the following changes take place: (1) it loses carbon dioxide, (2) it gains oxygen, which combines with the reduced hemoglobin of the red cells and turns it into oxyhemoglobin, and as a result of this the crimson color shifts to scarlet; and (3) the temperature is slightly reduced.

It is helpful to compare the average amounts of oxygen and carbon dioxide found in the venous blood brought to the lungs, and the amounts found in the arterial blood carried from the lungs.

	OXYGEN	CARBON DIOXIDE	NITROGEN
Venous blood contains.....	12%	45%	1.7%
Arterial blood contains.....	20%	38%	1.7%

The actual amounts of oxygen and carbon dioxide in the venous blood vary with the nutritive activity of the tissues, and differ therefore in the various organs according to the state of activity of each organ, and the volume of its blood-supply. There is always a considerable amount of oxygen in venous blood, also a considerable amount of carbon dioxide in arterial blood. Consequently, the main result of the respiratory exchange is to keep the gas content of the arterial blood nearly constant at the figures given. Under normal conditions it is not possible to increase appreciably the amount of oxygen absorbed by the blood flowing through the lungs.[11]

11 Student nurses sometimes find it difficult to reconcile this fact with the practice of using pure oxygen in critical cases of pulmonary disease. The relief of the pneumonia patient who inhales pure oxygen is usually marked because the blood absorbs an increased amount of oxygen. The reason for this seeming contradiction is that normal blood cannot absorb an increased amount of oxygen, but in the case of the pneumonia patient the composition of the blood as regards oxygen is below normal, and the inhalation of pure oxygen brings it up to the standard, hence the marked relief.

Diffusion of gases.—The passage of oxygen to, and of carbon dioxide from the blood is controlled by the laws of diffusion of gases,[12] There is more oxygen in the alveoli than in the pulmonary blood, hence the pressure is higher in the alveoli with the result that some of the oxygen passes from the alveoli into the blood in the capillaries. The same applies to the passage of carbon dioxide from the blood where the pressure is higher to the alveoli where the pressure is lower.

Oxygen, nitrogen and carbon dioxide.—A small portion of oxygen is held in solution, but by far the greater portion is held in chemical combination with the hemoglobin of the red cells. The amount of oxygen so held depends upon the quantity of hemoglobin in the blood, and the pressure of oxygen in the alveoli. It is thought that nitrogen in the blood is held in physical solution. It is probable that the carbon dioxide held in the blood is partly in solution, but by far the greater portion is carried as carbonates, mainly sodium bicarbonate.

Capacity of the lungs.—It has been stated that after the lungs are once filled with air they are never completely emptied again until after death. In other words, no expiration ever completely empties the alveoli, neither are they completely filled. The quantity of air which a person can expel by a forcible expiration, after the deepest inspiration possible, is called the vital capacity, and averages about 3500 to 4000 cc.[13] (7–8 pts.). It is the sum of tidal, complemental and supplemental air.

Tidal air designates the amount of air that flows in and out of the lungs with each quiet respiratory movement. The average figure for the adult is 500 cc. (1 pt.).

Complemental air designates the amount of air that can be breathed in over and above the tidal air by the deepest possible inspiration. It is estimated at 1600 cc. (3 pts.).

Supplemental air is the amount of air that can be breathed out after a quiet expiration by the most forcible expiration. It is equal to 1600 cc.

Residual air is the amount of air remaining in the lungs after the most powerful expiration. This has been estimated on the cadaver and is about 1000 cc. (2 pts.).

[12] The share of the total pressure which can be referred to any gas in a mixture is said to be the *partial pressure* of that gas. See discussion of the laws of *partial pressure* of gases in any textbook of chemistry or physics.

[13] These figures are approximate:

16.386 cc. = 1 cu.in.
568 cc. = 1 pt.
8 pts. = 1 gal.

Reserve air equals the residual air plus the supplemental air in the lungs under condition of normal breathing, that is, about 2600 cc. (5 pts.).

Minimal air.—When the thorax is opened the lungs collapse driving out the supplemental and residual air, but before the alveoli are entirely emptied the small bronchi leading to them collapse, and entrap a little air in the alveoli. The small amount of air caught in this way is designated as minimal air. It is due to minimal air that excised lungs of animals float in water and are called lights by the butcher.[14]

The inspired and expired air.—As the expirations never completely empty the lungs of air it follows that air entering with each fresh breath becomes mixed with that remaining in the alveoli. Consequently the air in the alveoli is never quite the same as inspired air, but normally the difference is not great. The composition of inspired air (atmospheric) varies in different places, but from a physiological standpoint the essential constituents are oxygen, nitrogen, and carbon dioxide. The new elements, argon, krypton, etc., have no physiological significance. In average figures the composition of inspired and expired air in volumes per cent is:—

	OXYGEN	CARBON DIOXIDE	NITROGEN
Inspired air	20.96%	0.04%	79%
Expired air	16.02%	4.38%	79%
	4.94 loss	4.34 gain	0

This table shows that in passing through the lungs, the air gains 4.34 volumes of carbon dioxide to each hundred and loses 4.94 volumes of oxygen. This is the main fact of external respiration. Three other changes occur.

1. However dry the external air may be, the expired air is quite, or nearly, saturated with moisture. An average of about one pint of water is eliminated daily in the breath.

2. Whatever the temperature of the external air, the expired air is nearly as hot as the blood; namely, of a temperature between 98° and 100° F. (36.7° and 37.8° C.).

3. The heat required to warm the expired air and vaporize the

[14] Before birth the lungs are solid. If after birth respirations are made, the lungs do not collapse completely on account of the capture of minimal air. Whether or not the lungs will float has constituted one of the facts used in medico-legal cases to determine if a child was still-born. See Howell's "Textbook of Physiology," Ninth edition, Page 653.

moisture is taken from the body and represents a daily loss of heat. It requires about 0.5 large Calorie to vaporize a gram of water.[15]

Ventilation.[16]—Since at every breath the external air gains carbon dioxide and loses oxygen, it was formerly taught that the general discomfort, headache, and languor that result from sitting in a badly-ventilated room were due solely to the increase in carbon dioxide and the loss of oxygen. The results of many experiments seem to prove that the air in badly-ventilated rooms does not vary in oxygen and carbon dioxide content as much as had been supposed, though odors given off from the body and its clothing when present in any amount may affect the nervous system disagreeably. It is now thought that the injurious effects of remaining in a badly-ventilated room are due to interference with the heat-regulating mechanism of the body. Under favorable conditions the surface of the human body is kept comfortably cool by the air currents which pass over it and by the evaporation of perspiration. In a confined space there is a lack of movement in the air and it tends to become warm and humid. Moisture is not taken from the skin promptly and the temperature rises. This results in a dilatation of the blood-vessels of the skin and an increased amount of blood is sent to the surface of the body, thereby increasing the unpleasant warmth. There is likely to be some reduction of the general blood-pressure leading to drowsiness or at least a feeling of inertia. In accordance with these views, the most effective precautions that can be taken to secure comfort in a room are to keep it cool and have some circulation of air. It has been shown that starting an electric fan in a close room may relieve an almost intolerable condition as it favors the removal of heat from the bodies of the inmates and braces up their vasomotor systems. One writer suggests that the real difficulty with a stuffy room is that there is a lack of stimulation for the nervous system. One becomes relaxed and indolent because the nerve-endings in the skin are not being played upon as they would be by a constant change in environmental conditions. Because of these facts we are now taught that proper ventilation requires that (1) there must be continuous movement of the air; (2) the temperature and degree of humidity must favor the evaporation of perspiration from the skin. Various experiments indicate that the optimal conditions approximate a temperature of 60°–65° F. (15°–18° C.), and a

[15] See pages 447 and 449.

[16] For discussion of Ventilation, see Public Health and Hygiene by Park, W. H., Chapter VII.

relative humidity of 50–60 per cent. (3) Odors from skin, clothing, light, and other sources must be eliminated. These requirements can only be met if the size of occupied rooms is in proportion (*a*) to the number of people occupying them; (*b*) to the facilities for ventilation; and (*c*) to the degree of air contamination likely to occur.

Internal respiration.—The exchange of gases in the tissues constitutes internal respiration and consists of (1) the passage of oxygen from the blood into the lymph, and from the lymph into the tissue cells, and (2) the passage of carbon dioxide from the tissue cells into the lymph, and from the lymph into the blood.

After the exchange of gases in the lungs, the aërated blood is returned to the heart, and distributed to all parts of the body. In passing through the capillaries the blood is brought into exchange with a surrounding medium—lymph—in which the oxygen pressure is low. The compound of oxygen and hemoglobin, oxyhemoglobin, is only stable in an environment where the oxygen pressure is relatively high. Consequently the blood in passing through the capillaries gives up much of its oxygen, which passes to the lymph and from the latter to the tissue cells. On the contrary, the pressure of carbon dioxide is higher in the cells than in the blood, and this facilitates the passage of carbon dioxide from the cells to the lymph, and from the latter to the blood. A small amount of the carbon dioxide entering the capillaries remains in solution, but most of it combines with alkaline material in the blood, thereby forming salts, chiefly sodium bicarbonate ($HNaCO_3$).

It is important to remember that the blood does not give up all its oxygen to the tissues, nor all of its carbon dioxide in the lungs.[17] Excessive amounts of carbon dioxide will cause death by asphyxia, but in normal amounts it is as essential to life as oxygen. Due to its specific effect on the respiratory center it is the means of regulating the rate of the respirations.

RESPIRATORY PHENOMENA

Each intake of air is accompanied by a fine rustling sound which can be heard if the ear is applied to the chest wall. It is thought that the dilatation of the alveoli produces this sound, and absence of it indicates that the air is not entering the alveoli over which no sound is heard, or that the lung is separated from the

[17] See page 315.

chest wall by effused fluid. The air passing in and out of the larynx, trachea and bronchial tubes produces a louder sound which is called a bronchial murmur. Normally this murmur is heard directly above or behind the tubes, but when the lung is consolidated as in pneumonia, it conducts sound more readily than usual and the murmur is heard in other parts of the chest. In diseased conditions the normal sounds are modified in various ways, and are then spoken of under the name of *râles*.

Eupnea.—This term is applied to ordinary quiet respiration made without obvious effort.

Dyspnea.—The word dyspnea is applied to difficult or labored breathing. It is caused by (1) an increase in the percentage of carbon dioxide in the blood, (2) a decrease in the oxygen, (3) any condition that stimulates the sensory nerves and causes pain

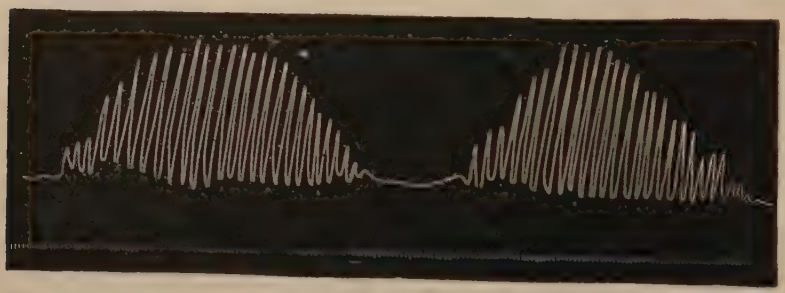


FIG. 186.—STETHOGRAPH TRACING OF CHEYNE-STOKES RESPIRATIONS IN A MAN. The time is marked in seconds. (Halliburton.)

in the lungs, and (4) any condition that interferes with the normal *rate* of the respirations or of the heart action, or prevents the passage of air in and out of the lungs.

Hyperpnea.—The word hyperpnea is applied to the initial stages of dyspnea, when the respirations are simply increased.

Apnea.—The word apnea means a lack of breathing.

Cheyne-Stokes respirations.—This is a type of respirations which was first described by the two physicians whose names it bears. It appears in two forms: (1) the respirations increase in force and frequency up to a certain point, and then gradually decrease until they cease altogether, and there is a short period of apnea, then the respirations recommence and the cycle is repeated. (2) The respirations increase in force and frequency up to a certain point, then cease, and the period of apnea intervenes, without the gradual cessation of the respirations. Its actual

cause is not understood, but it is associated with conditions that depress the respiratory center, especially in brain, heart and kidney diseases.

Edematous respiration.—When the air cells become infiltrated with fluid from the blood, the breathing becomes edematous and is recognized by the moist, rattling sounds, called râles, caused by the passage of the air through the fluid. It is a serious condition because it interferes with aëration of the blood and often results in asphyxia.

Asphyxia.—Asphyxia is produced by any condition that causes prolonged interference with the aeration of the blood, *viz.*, obstruction to the entrance of air to the lungs, depression of the respiratory center, an insufficient supply of oxygen, or a lack of hemoglobin in the blood. The first stages are associated with dyspnea and convulsive movements, then the respirations become slow and shallow and are finally reduced to mere twitches. The skin is cyanosed, the pupils of the eyes dilate, the reflexes are abolished and respirations cease. If the heart continues to beat, resuscitation is often accomplished by artificial respiration even after breathing has ceased.

Phonation.—This term is applied to the production of vocal sounds. All of the respiratory organs function in the production of vocal sounds, but the vocal folds, the larynx, and the parts above are specially concerned. The speech centers and parts of the brain which control the movements of the tongue and jaw, also the tongue itself, are of special importance. The organs of phonation in man are similar to those of many animals much lower in the scale of life, but the association areas of the brain account for the greater variety of sounds that man can produce.

Voice.—The vocal folds produce the voice. A blast of air, driven by an expiratory movement out of the lungs, throws the two elastic folds into vibrations. These impart their vibrations to the column of air above them, and so give rise to the sound which we call the voice. The pharynx, mouth, and nasal cavities above the glottis act as resonating cavities. The volume and force of the expiratory blast and the amplitude of the vibrations of the vocal folds, determine the loudness or intensity of the voice. The pitch of the voice depends upon the number of vibrations occurring in a given unit of time. This in turn is dependent on the length, thickness, and degree of elasticity of the vocal folds, and the tension by which they are held. When

the folds are tightly stretched and the glottis almost closed, the highest sounds are emitted. (See Fig. 182.)

Differences between the male and female voice.—The size of the larynx varies in different individuals and this is one reason for differences in pitch. At the time of puberty, the growth of the larynx and the vocal folds is much more rapid and accentuated in the male than in the female. The increase in the size of the larynx causes an increase in the length of the vocal folds, and also gives rise to what is commonly called Adam's apple. These changes in structure are accompanied by changes in the voice, which becomes deeper and lower. Before the characteristic adult voice is attained, there occurs what is described as a break in the voice, due to the inability of the individual to control the longer vocal folds. It is thought that the development of the larynx and the consequent change of voice in the male depends upon the development of the sexual organs, because castration in early life tends to prevent this change, the voice retains the high pitch of youth and is considered effeminate.

SUMMARY

Respiration
- All living organisms require continual supply of oxygen.
- Chemical changes in tissue cells dependent upon it.
- Carbon dioxide is one end-product of chemical changes in cells, hence need for elimination of excess.
- Exchange of these gases in lungs and cells constitutes respiration.

Essentials of human respiratory system
- (1) Air containing a high percentage of oxygen on one side.
- (2) Moist and permeable membrane.
- (3) Moving stream of blood with a high percentage of carbon dioxide on other side.

Respiratory System
- Air passes through nose or mouth to
  1. Larynx.
  2. Trachea.
  3. Bronchi.
  4. Lungs.

Nose

Function
- Special organ of the sense of smell.
- Passageway for entrance of air to the respiratory organs
- Helps in phonation.

External nose
- Framework of bone (nasal) and cartilage.
- Covered with skin, lined with mucous membrane.
- Nostrils are oval-shaped openings on under surface separated by a partition.

Internal cavities, or nasal fossæ
- Two wedge-shaped cavities.
- Extend from nostrils to the pharynx.
- Lined by mucous membrane, vascular and ciliated.
- Formed by
  - 2 palatine.
  - 2 maxillæ.
  - 1 ethmoid.
  - 1 sphenoid.
  - 2 nasal.
  - 2 conchæ, and processes of the ethmoid.
    - Superior meatus.
    - Middle meatus.
    - Inferior meatus.
  - 1 vomer.
  - —
  - 11 bones.

Advantages of nasal breathing
- Air
  - Warmed.
  - Moistened.
  - Filtered.

Communicating sinuses
1. Frontal.
2. Ethmoidal.
3. Maxillary or antra of Highmore.
4. Sphenoidal.

Larynx
- Special organ of voice.
- Triangular box made up of nine pieces of cartilage.
- Situated between the tongue and trachea.
- Contains vocal folds.
- Slit or opening between cords called *glottis*, which is protected by leaf-shaped lid called epiglottis.
- Connected with external air by
  - Mouth.
  - Nose.
- Nerves—from sympathetic and the cranial autonomic nerves.

Trachea

- Fibrous and muscular tube, 4½ in. long.
- Strengthened by C-shaped rings of cartilage
  - Complete in front.
  - Incomplete behind.
- In front of esophagus.
- Extends from larynx to fifth thoracic vertebra, where it divides into two bronchi.
- Nerves—from sympathetic and cranial autonomic nerves.

Bronchi and Bronchioles

- Right and left—structure similar to trachea.
  - Right
    - 1 in. long.
    - Almost vertical.
  - Left
    - 2 in. long.
    - Almost horizontal.
- Divide into innumerable bronchial tubes or bronchioles.
- As tubes divide their walls become thinner. Finer tubes consist of thin layer muscular and elastic tissue lined by ciliated epithelium.
- Each bronchiole terminates in funnel-like enlargement called atrium (*infundibulum*).
- From each atrium a series of sac-like projections known as *alveoli*, or air cells arise.

Lungs

- **Location**—Lateral chambers of thoracic cavity separated by structures contained in mediastinum.
- **Cone-shaped organs**
  - Outer surface convex to fit in concave cavity.
  - Base concave to fit over convex diaphragm.
  - Apex about an inch or an inch and one-half above the level of sternal end of first rib.
  - Hilum or depression on inner surface gives passage to bronchi, blood-vessels, lymphatics, and nerves.
- **Right**—Larger, heavier, broader, shorter—three lobes.
- **Left**—Smaller, narrower, longer, front border deeply indented—two lobes.
- **Anatomy**—Porous, spongy organs. Consist of bronchial tubes—atria—alveoli, also blood-vessels, lymphatics, and nerves held together by connective tissues.
- **Blood-vessels**
  - **Pulmonary artery**
    - Blood for aeration.
    - Accompanies bronchial tubes.
    - Plexus of capillaries around alveoli.
    - Returned by pulmonary veins.
  - **Bronchial arteries**—supply lung substance.

Pleura

- Closed sac. Envelops lungs, but they are not in it.
- Two layers
  - Pulmonary or Visceral—next to lung
  - Parietal—outside of visceral
    - Normally in close contact — potential cavity.
    - Moistened by serum.
- **Function**—To lessen friction.
- Pleurisy—inflammation of pleura.

Mediastinum

- Space between pleural sacs. Extends from sternum to spinal column. Contains the heart, large blood-vessels connected with heart, part of thoracic duct, thymus or vestiges of it, trachea, esophagus, portions of the vagus and phrenic nerves.

Respiration

- **Function**
  - Increase the amount of oxygen.
  - Decrease the amount of carbon dioxide.
  - Help to maintain temperature.
  - Help to eliminate waste.
- **Processes**
  - **Breathing**
    - **Inspiration**—Process of taking air into lungs.
    - **Expiration**—Process of expelling air from lungs.
  - **External Respiration** (Takes place in the lungs.)
    - External oxygen supply
    - External carbon dioxide elimination
  - **Internal Respiration** (Takes place in the cells.)
    - Internal oxygen supply
    - Internal carbon dioxide elimination

Mechanism of Inspiration and Expiration

- **Respiratory movements** consist of alternate outward and inward movement of walls of thorax, increase followed by decrease in capacity of cavity, corresponding distension and recoil of lungs.
- **Enlargement of cavity**
  - Dorso-ventral.
  - Lateral.
  - Vertical (antero-posterior).
- **Inspiration**
  - Chest cavity enlarged
    - Elvation of ribs, an active process dependent upon contraction of muscles of inspiration.
    - Descent of diaphragm by contraction of diaphragmatic muscles.
  - Enlargement of lungs—in proportion to enlargement of cavity—lungs in contact with chest walls.
  - Air rushes in through trachea and bronchi.
- **Expiration**
  - Chest cavity made smaller
    - Inspiratory muscles relax.
    - Recoil of elastic thorax.
    - Recoil of elastic lungs.
  - Air forced out through trachea.

Muscles of Inspiration

- All the muscles that function in enlargement of the chest cavity.
- The diaphragm.
- The levatores costarum.
- The external intercostals.
- The scaleni.
- The sternocleidomastoid.
- The pectoralis minor.
- The serratus posticus superior.

Muscles of Expiration

- All the muscles that function in diminution in size of chest cavity. Accomplished in two ways:
- 1. Force diaphragm farther up into thoracic cavity
  - Contraction of muscular walls of the abdomen, *i.e.*, the external and internal oblique, the rectus and transversalis.
- 2. Depress the ribs
  - Internal intercostals.
  - Transversus thoracis.
  - Some authorities add
    - Iliocostalis.
    - Serratus posticus inferior.
    - Quadratus lumborum.

Types of Respiration

- Costal—expansion of thoracic walls and lungs limited—ribs move upward.
- Abdominal—expansion of thoracic wall and lungs greater—resultant respiration deeper—abdomen bulges outward.

Respiratory Center
- Located in medulla oblongata.
  - Center for inspiration is respiratory center.
  - Center for expiration—assumed.
- Efferent fibers from respiratory center travel down spinal cord and connect with fibers of vagi and sympathetic nerves distributed in the lung tissue.
- Afferent nerves lead to the respiratory center.
- Connection with the sensory fibers of all the cranial and spinal nerves assumed.
- **Action**
  - Automatic, *i.e.*, it is constantly sending impulses over afferent fibers.
  - **Rate and rhythm dependent on**
    - Vagi nerves
      - Two kinds of fibers:
      - 1—inhibits inspiration.
      - 2—inhibits expiration.
    - Chemical condition of blood, *i.e.*, amount of carbon dioxide.

Oxygen Content of Blood Reduced
1. Interference with circulation in lungs.
2. Decreased number of red cells in blood.
3. Interference with passage of air to lungs, or reduced amount of oxygen in alveoli.

Control of Respiration
- Voluntary control for a short time.
- Involuntary control due to specific irritability of respiratory center for oxygen.

Cause of First Respiration
1. Increased amount of carbon dioxide due to cutting of the umbilical cord.
2. Reflex, due to stimulation of the sensory nerves of the skin.

Respiratory Rate
- 14 times per minute
- Influenced by
  - Muscular exercise.
  - Emotion.
  - Heart beat.
  - Age.

External Respiration
- Takes place in lungs.
- **Blood**
  - Loses about 7% of carbon dioxide.
  - Gains about 8% of oxygen
    - Oxyhemoglobin.
    - Scarlet color.
  - Temperature is slightly reduced.
- Exchange dependent on laws of diffusion of gases.

Capacity of Lungs
- After lungs are once filled they are never emptied during life.
- Vital capacity—quantity of air person can expel by forcible expiration after deepest inspiration possible—averages from 3500 to 4000 cc.
- **Terms in use**
  - Tidal.
  - Complemental.
  - Supplemental.
  - Residual.
  - Reserve.
  - Minimal.

Inspired and Expired Air

- **Changes effected**
  1. Moisture increased. Expired air is saturated with moisture.
  2. Temperature increased. Expired air is as hot as blood.
  3. Heat to warm air and vaporized moisture taken from body.
  4. Oxygen decreased by 4.94%.
  5. Carbon dioxide increased by 4.34%.

Ventilation Requirements

1. Continuous movement of the air.
2. The temperature and degree of humidity must favor the evaporation of perspiration from the skin.
   Optimal conditions approximate a temperature of 60 to 65° F. (15° C. to 18° C.) and a relative humidity of 50 to 60 per cent.
3. Disagreeable odors must be eliminated.

Internal Respiration

- Exchange of gases in the tissues.
- Consists of
  - Passage of oxygen from blood into lymph, and from lymph into cells.
  - Passage of carbon dioxide from tissue cells into lymph, and from lymph into blood.
- Important to remember blood does not give up all its oxygen to the tissues, nor all of its carbon dioxide in the lungs.

Respiratory Phenomena

- Air passing into alveoli produces a fine rustling sound.
- Air passing in and out of larynx, trachea and bronchial tubes produces louder sound called bronchial murmur.
- In diseased conditions modified sounds are called *râles*.
- Eupnea—ordinary quiet respiration.
- Dyspnea—difficult breathing.
- Hyperpnea—excessive breathing.
- Apnea—lack of breathing.
- Cheyne-Stokes
  1. Respirations increase in force and frequency, then gradually decrease and stop. Cycle repeated.
  2. Respirations increase in force and frequency up to a certain point, then stop. Cycle repeated.
- Edematous—air cells filled with fluid, hence moist, rattling sounds.
- Asphyxia—oxygen starvation.

Phonation

- **Phonation**—production of vocal sounds.
- **Organs of Phonation**
  - Respiratory organs.
  - Vocal folds
    - Lower pitch of male voice is due to greater length of vocal folds.
  - Larynx, pharynx, mouth, nose and tongue.
  - Speech centers and parts of brain which control movements of the tongue and jaw, also association centers.

CHAPTER XVII

THE DIGESTIVE SYSTEM: ALIMENTARY CANAL AND ACCESSORY ORGANS

In complex multicellular bodies, the cells where food is needed are so far removed from the points of entrance of food material, that it is necessary that these foods should be changed physically and chemically into such standard substances as can diffuse into the blood-stream and be carried to all the cells of the body and diffuse into them. Chemical and physical changes necessary to reduce our varied foods to such standard substances as the tissues can use are effected in certain organs that are grouped together and called the digestive system.

THE DIGESTIVE SYSTEM

The digestive system consists of the alimentary canal and the accessory organs: (1) the salivary glands, (2) the tongue, (3) the teeth, (4) the pancreas, and (5) the liver.

Alimentary canal.—The alimentary canal is a continuous tube which extends from the mouth to the anus. It measures about 30 feet (9 m.) in length, the greater part being coiled up in the cavity of the abdomen. From the pharynx to the rectum it is composed of four coats. Beginning at the inner lining these coats are:—

(1) The **mucous.**
(2) The **sub-mucous** or **areolar** } Both described in Chapter IX.

(3) The **muscular** coat consists almost entirely of non-striated muscular tissue, usually arranged in two layers. The internal cells are circular in direction, and the external cells run longitudinally. By the alternate contraction and relaxation of cells arranged in this fashion (the contractions starting from above), the contents of the tube are propelled from above downward.

(4) The esophagus is above the diaphragm and the outer coat is **fibrous.** Below the diaphragm the fourth coat is **serous** and is derived from the peritoneum.

The peritoneum.—This is the largest serous membrane in the body and in the male consists of a closed sac,[1] the parietal layer of which lines the walls of the abdominal cavity; the inner or

[1] In the female the peritoneum is not a closed sac, because the Fallopian tubes open into it at their extremities.

visceral layer is reflected over the abdominal organs, and the upper surface of some of the pelvic organs. The arrangement of the peritoneum is very complex, for several elongated sacs and double folds extend from it, to pass in between and either wholly or partially surround the viscera of the abdomen and pelvis. One important fold is the *omentum*, which hangs like a curtain in front of the stomach and the intestines; another is the *mesentery*, which is a continuation of the serous coat and attaches the small and much of the large intestine to the spine. (See Fig. 172.)

When the abdominal cavity is opened, the intestines appear to lie within the cavity like a loose coil of rope. If, however, an attempt is made to lift a coil from its place a clear, glistening sheet of tissue is found attached to it. This is the mesentery. The posterior portion is gathered into folds which are attached to the spine along a short line of insertion which results in a structure that has the appearance of a ruffle or flounce.

Function of the peritoneum.—Like all serous membranes the peritoneum serves to prevent friction between contiguous organs by secreting serum which acts as a lubricant. To a limited extent it serves to hold the abdominal and pelvic organs in position, also unites and separates these organs. In addition to these functions, the omentum usually contains fat, and serves to keep the organs it covers warm.

Divisions of the alimentary canal.—For convenience of description, the alimentary canal may be divided into:—

Mouth, containing tonsils, tongue, salivary glands, and teeth.
Pharynx.
Esophagus.
Stomach.

Small or thin intestine	Duodenum.	
	Jejunum.	
	Ileum.	
Large or thick intestine	Cecum.	
	Colon.	Ascending.
		Transverse or mesial.
		Descending.
		Sigmoid.
	Rectum.	
	Anal canal.	

Mouth, or buccal cavity.—The mouth cavity is a nearly oval-shaped cavity which is bounded in front by the lips, on the sides by the cheeks, below by the tongue, above by the palate, and at the back by the pharynx.

The palate.—The palate consists of a hard portion in front formed by bone[2] covered by mucous membrane, and of a soft portion behind containing no bone. The hard palate forms the partition between the mouth and nose; the soft palate arches

[2] Processes of the maxillæ and palatine bones.

backward and hangs like a curtain between the mouth and the pharynx. Hanging from the middle of its lower border is a pointed portion of the soft palate called the *uvula* (little grape).

Fauces.—The fauces is the name given to the aperture leading from the mouth into the pharynx, or throat cavity.

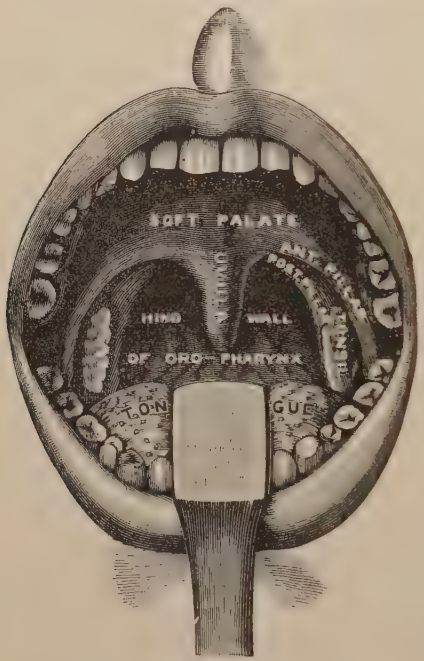


Fig. 187.—The Soft Palate and Tonsillar Regions. (Gerrish.)

Pillars of the fauces.—From the base of the uvula on either side there passes a curved fold of muscular tissue covered by mucous membrane, which shortly after leaving the uvula is, as it were, split into two pillars, the one going outward, downward, and forward, passing to the side of the tongue, the other outward, downward, and backward to the side of the pharynx. These pillars are known respectively as the *anterior* and the *posterior* pillars of the fauces.

Tonsils.—In the lower part of the triangular space between the anterior and posterior pillars, on either side, lie the small masses of lymphoid tissue called tonsils. They consist of a collection of lymph-nodules held together by a distinct capsule and covered on their exposed surface by mucous membrane.

Function.—The function of the tonsils is imperfectly understood. When in a normal condition, it is thought they help to protect the body from infection, by acting as filters and preventing the entrance of microörganisms. If they are abnormal their protective function is reduced, and they may serve as foci of infection which passes directly into the lymph and so into the blood. If they are much enlarged they tend to fill the throat cavity and interfere with the passage of air to the lungs. Inflammation of the tonsils is called tonsillitis.

The palate, uvula, pillars of the fauces, and tonsils are plainly seen if the mouth is widely opened and the tongue depressed.

The tongue.—The tongue[3] is the special organ of the sense of taste and assists in speech. It has also to be considered with reference to digestion, (1) because stimulation of the end-organs (taste buds) of the nerves of the sense of taste increases the secretion of saliva and starts the first flow of gastric fluid, (2) it assists in swallowing, and (3) the follicles at the back of the tongue secrete mucin, which lubricates the food and makes swallowing easier.

The salivary glands.—The mucous membrane lining the mouth contains many minute glands consisting of just one cell. These are called goblet cells and pour their secretion upon its surface, but the chief secretion of the mouth is supplied by the salivary glands, which are three pairs of compound saccular glands called the parotid, submaxillary, and sublingual, respectively. Each *parotid* gland is placed just under and in front of the ear; its duct (Stenson's) passes forward along the cheek, until it opens into the interior of the mouth opposite the second molar tooth of the upper jaw. The *submaxillary* and *sublingual* glands are situated below the jaw and under the tongue, the submaxillary being placed farther back than the sublingual. One duct from each submaxillary and a number of small ducts from each sublingual open in the floor of the mouth beneath the tongue. The secretion of these salivary glands, mixed with that of the small glands of the mouth, is called saliva.

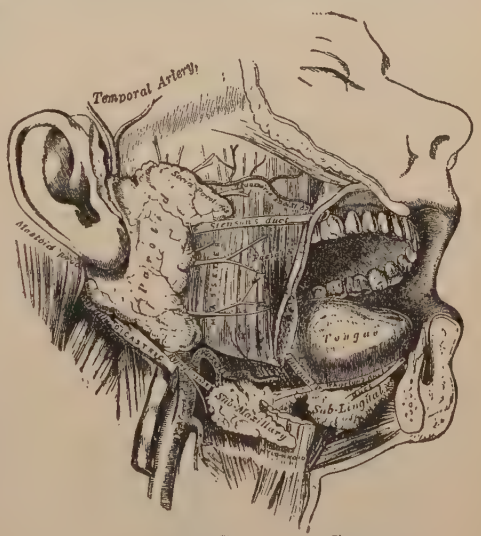


FIG. 188.—THE SALIVARY GLANDS.

Nerves.—The salivary glands receive a double nerve supply, —in part from the cranial nerves (the facial and glosso-pharyngeal), and in part from the autonomic system. The facial nerve supplies secretory fibers to the submaxillary and sublingual, and vasodilator fibers to the blood-vessels of these glands. The glossopharyngeal nerve supplies secretory fibers to the parotid

[3] A detailed description of the tongue will be found in Chapter XXII.

gland. While these nerves are cranial in their origin, from the standpoint of function (secretion and dilatation of blood-vessels) they belong to the autonomic system. Stimulation of the vasodilator fibers dilates the small arteries and increases the blood-supply. The sympathetic nerves carry vasoconstrictor fibers that constrict the arteries and diminish the blood-supply.

The teeth.—The semicircular borders of the upper and lower jaw-bones (the alveolar processes) contain sockets for the reception of the teeth. A dense, insensitive, fibrous membrane covered by smooth mucous membrane—the gums—covers these processes and extends a little way into each socket. These sockets are lined by periosteum, which connects with the gums and serves (1) to attach the teeth to their sockets, and (2) as a source of nourishment.

Each tooth consists of three portions: (1) the *root*, consisting of one or more fangs contained in the socket; (2) the *crown*, which projects beyond the level of the gums; and (3) the *neck* or constricted portion between the root and the crown, which is enveloped by the gum.

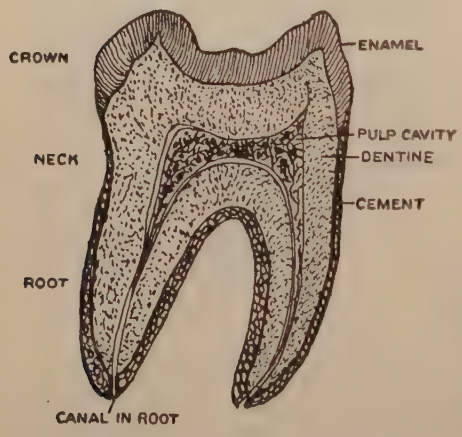


FIG. 189.—SECTION OF HUMAN MOLAR TOOTH. (Adapted from Dalton.)

Each tooth is composed principally of *dentin*, which gives it shape and encloses a cavity, the pulp cavity. The dentin of the crown is capped with a dense layer of *enamel*. The dentin of the root is covered by *cement*. These three substances, enamel, dentin, and cement, are all harder than bone, enamel being the hardest substance found in the body. They are developed from epithelial tissue. The pulp cavity is just under the crown and is continuous with a canal that traverses the center of each root, and opens by a small aperture at its extremity. It is filled with dental pulp, which consists of loose connective tissue holding a number of blood-vessels and nerves which enter by means of the canal from the root.

There are two sets of teeth developed during life: the first, temporary or deciduous; and the second, permanent.

Temporary teeth.—In the first set are twenty teeth, ten in each jaw: four incisors, two canines, and four molars. The cutting of the temporary teeth usually begins at six months and ends at about the age of two years. In nearly all cases the teeth of the lower jaw appear before the corresponding ones of the upper jaw.

TEMPORARY TEETH

	MOLARS	CANINE	INCISORS	CANINE	MOLARS
Upper	2	1	4	1	2
Lower	2	1	4	1	2

The temporary teeth are usually cut in the following order:—

Lower central incisors	6 to 9 months
Upper incisors	8 to 10 months
Lower lateral incisors and first molars	15 to 21 months
Canines	16 to 20 months
Second molars	20 to 24 months

Permanent teeth.—During childhood the temporary teeth are replaced by the permanent. In the second set are thirty-two permanent teeth, sixteen in each jaw. The first molar usually appears between five and seven years of age.

PERMANENT TEETH

	MOLAR	PREMOLAR	CANINE	INCISOR	CANINE	PREMOLAR	MOLAR
Upper	3	2	1	4	1	2	3
Lower	3	2	1	4	1	2	3

The permanent teeth appear at the following periods:—

First molars	6 years
Two central incisors	7th year
Two lateral incisors	8th year
First premolars	9th year
Second premolars	10th year
Canine	11th to 12th year
Second molars	12th to 13th year
Third molars	17th to 25th year

There are considerable individual variations in the time of eruption of both the temporary and permanent teeth. The figures given by different authorities also vary. According to their shape and use the teeth are divided into incisors, canines, premolars or bicuspids, and molars.

Incisors are eight in number and form the four front teeth of each jaw. They have wide, sharp edges, and are specially adapted for cutting food.

Canines are four in number, two in each jaw. The upper canines are commonly called eye teeth; the lower, stomach teeth. They have sharp, pointed edges and are longer than the incisors. In the human being they serve the same purpose as the incisors.

Premolars or bicuspids are eight in number in the permanent set. There are none in the temporary set. There are four in each jaw, two being placed just behind each of the canine teeth.

They are broad, with two points or cusps on each crown; these teeth have only one root; the root, however, being more or less completely divided into two. Their function is to cut and grind food.

Molars are twelve in number in the permanent set, and only eight in the temporary set. They have broad crowns with small, pointed projections, which make them well fitted for crushing and bruising the food: they each have two or three roots. The twelve molars do not replace the temporary teeth, but are gradually added with the growth of the jaws; the last or hindmost molars may not appear until twenty-five years of age; hence called *late teeth* or *"wisdom teeth."*

Long before the teeth appear through the gums their formation and growth are in progress. The temporary set begins to develop about the sixth week of intrauterine life; and the permanent set, with the exception of the second and third molars, begins to develop about the sixteenth week. About the third month after birth, the second molars begin to grow, and about the third year the third molars or wisdom teeth do likewise. Diseases such as rickets and marasmus retard the eruption of the temporary teeth, and severe illness during childhood may interfere with the normal development of the permanent teeth so that they are marked with notches and ridges. Moreover cavities form in them readily. When the central incisors are notched along their cutting edges and the lateral incisors are pegged, they are named Hutchinson's teeth, and are a diagnostic sign of congenital syphilis.

Function.—The teeth assist in the process of mastication by cutting and grinding the food. It might be thought that the vigorous employment of the teeth for this purpose would only hasten their wear and tear. This may be true at a time when their life is nearly extinct, but at an earlier period mastication of the more solid foods is good for the teeth because they are made to sink and rise in their sockets with a massaging effect upon the gums which tends to promote circulation in the pulp. Proper

cleansing of the mouth and teeth tends to prevent the formation of cavities. If particles of food are allowed to remain in the mouth, there is always the danger of the bacteria in the mouth acting upon them and producing acid fermentation, in which case the acid erodes the alkaline enamel and dentin.

The pharynx.—The pharynx, or throat cavity, is a musculo-membranous tube shaped somewhat like a cone, with its broad end turned upward and its constricted end downward to end in the esophagus. It is about five inches (12.5 cm.) in length. Above, it is attached to the base of the skull, and behind, to the cervical vertebræ; in front and on each side are apertures which communicate with the nose, ears, mouth, and larynx. Of these apertures there are **seven**:—

Two in front above, leading into the back of the nose, the posterior nares. The upper portion which opens into the nose is called the naso-pharynx.

Two, one on either side above, leading into the Eustachian tubes, which communicate with the ears.

One midway in front, the fauces, connecting with the mouth in front. When the mouth is open and the tongue depressed, one looks through the fauces and the part seen is called the oro-pharynx.

Two below, one opening through the glottis into the larynx and the other into the esophagus. The lowest portion of the pharynx is called the laryngo-pharynx.

The mucous membrane lining the pharynx is well supplied with glands, and at the back and upper part of the cavity there is a considerable mass of lymphoid tissue. During infancy and childhood this may increase to such an extent that the child is said to have *adenoids*. Adenoids are a menace to health because (1) they may block the Eustachian tubes, and in some cases cause deafness, (2) they interfere with the passage of air through the nose; and necessitate (*a*) mouth breathing, which allows dust and other foreign matters to pass into the lungs, and tends to alter the shape of the jaws, (*b*) forced breathing, which tends to alter the shape of the chest; (3) their presence constantly stimulates the afferent nerves, and this continuous inflow of impulses to the nerve centers results in fatigue of these centers. This produces discomfort and abnormal nervous conditions.

Function.—The pharynx (1) transmits the air from the mouth or nose to the larynx, and (2) serves as a resonating cavity in the

production of the voice. (3) The muscular tissue in the walls of the pharynx is of the striped variety, and when the act of swallowing is about to be performed, the muscles draw the pharynx upward and dilate it to receive the food; they then relax, the pharynx sinks, and the other muscles contracting upon the food, it is pressed downward and onward into the esophagus.

The esophagus, or gullet.—The esophagus is a comparatively straight tube, about nine to ten inches (22.5 cm. to 25 cm.) long,

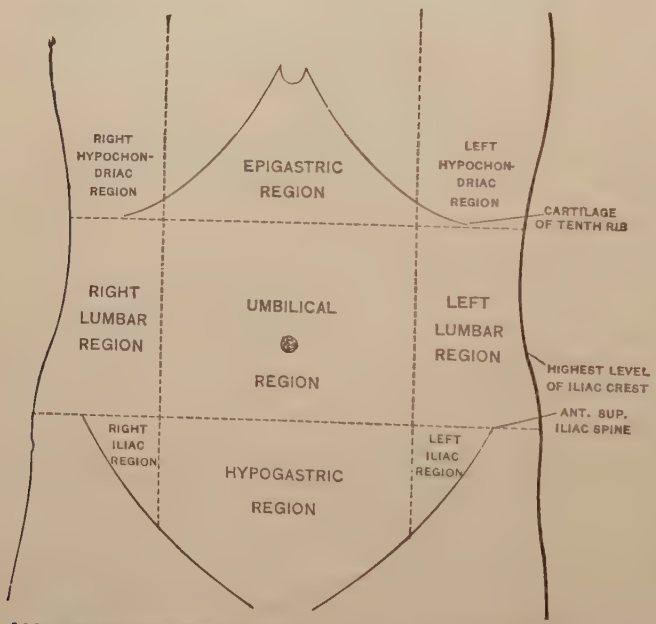


FIG. 190.—For convenience of description, the abdomen may be artificially divided into nine regions by drawing the following arbitrary lines:—1. Draw a circular line around the body at the level of the tenth costal cartilages. 2. Draw another circular line at the level of the anterior superior spines of the ilia. 3. Draw a vertical line on each side from the center of Poupart's ligament upward. These lines are to be considered as edges of planes which divide the abdomen into the nine regions. (Gerrish.)

which commences at the lower end of the pharynx, behind the trachea. It descends in front of the spine, passes through the diaphragm, and terminates in the upper or cardiac end of the stomach.

Structure.—The walls of the esophagus are composed of four coats: (1) an external or fibrous, (2) a muscular, (3) a sub-

mucous or areolar, and (4) a mucous or internal, coat. The muscular coat is arranged in an external longitudinal and an internal circular layer. Contraction of the outer layer produces dilatation of the tube; contraction of the inner, constriction. Consequently this arrangement is of importance in the movements which carry the food from the pharynx to the stomach. These movements are called peristaltic, and consist of contractions of the longitudinal layer, followed by contractions of the circular layer. The areolar coat serves to connect the muscular and mucous coats. The mucous membrane is disposed in longitudinal folds which disappear upon distention of the tube, caused by the passage of food. It is studded with minute papillæ and small glands which secrete mucus to lubricate the canal.

Function.—The esophagus serves (1) to connect the pharynx with the stomach, and (2) to receive the food from the pharynx and by a series of peristaltic contractions pass it on to the stomach.

THE STOMACH

After the esophagus perforates the diaphragm it ends in the stomach (gaster), which is a collapsible sac-like dilatation of the alimentary canal and serves as a temporary receptacle for food. It lies obliquely in the epigastric and left hypochondriac regions of the abdomen, directly under the diaphragm. The shape and position of the stomach are modified by changes within itself, and in the surrounding organs. These modifications are determined by (1) the amount of the stomach contents, (2) the stage of digestion which has been reached, (3) the degree of development and power of the muscular walls, and (4) the condition of the adjacent intestines. It is never entirely empty but always contains a few cc. of gastric fluid and mucin. When contracted the shape of the stomach is comparable to a sickle or sausage. At an early stage of gastric digestion, the stomach usually consists of two segments, a large globular portion on the left, and a narrow tubular portion on the right. When distended with food it has the shape shown in Fig. 192. The stomach presents two openings and two borders or curvatures.

Openings.—The opening by which the esophagus communicates with the stomach is known as the cardiac or esophageal

orifice, and the orifice which communicates with the duodenum is known as the pyloric. Both the cardiac and pyloric apertures are guarded by ring-like muscles known as sphincters which when contracted keep the orifices closed. They are contracted except when food is passing through them. By this arrangement, the food is kept in the stomach until it is ready for intestinal digestion when the circular fibers guarding the pyloric aperture relax. The acidity of the stomach contents seems to produce this relaxation.

Curvatures.—In all positions the stomach is more or less curved upon itself. A line drawn from the cardiac orifice along the con-

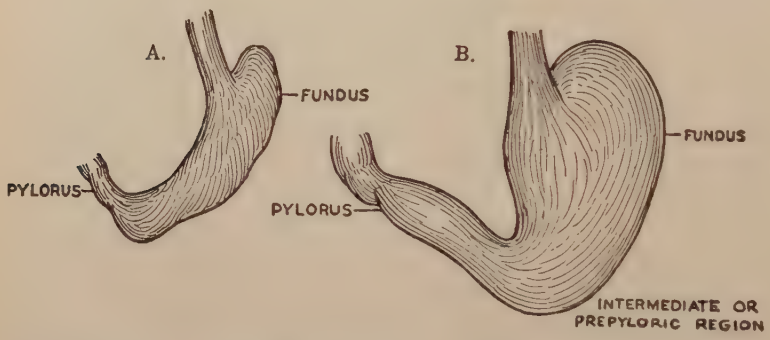


FIG. 191.—FORM AND OUTLINE OF THE STOMACH AT DIFFERENT STAGES OF DIGESTION. *A*, when contracted. *B*, at an early stage of gastric digestion.

cave border to the pyloric orifice is said to follow the lesser curvature. A much longer line connecting the same points, but following the convex border, defines the greater curvature.

Component parts.—The fundus is the blind rounded end of the stomach to the left of the heart. The opposite or smaller end is called the pyloric extremity and lies under the liver. The central portion between the fundus and pyloric extremity is called the intermediate or prepyloric region.

Structure.—The wall of the stomach consists of four coats: (1) serous, (2) muscular, (3) submucous or areolar, and (4) mucous.

(1) The **serous** coat is formed by a fold of the peritoneum. This fold is thrown over the stomach and covers it before and behind. The anterior and posterior folds unite at the lower

border and form an apron-like appendage, the *omentum*, which is suspended in front of the intestines.

(2) The **muscular** coat of the stomach is beneath the serous coat and closely connected with it. It consists of three layers of

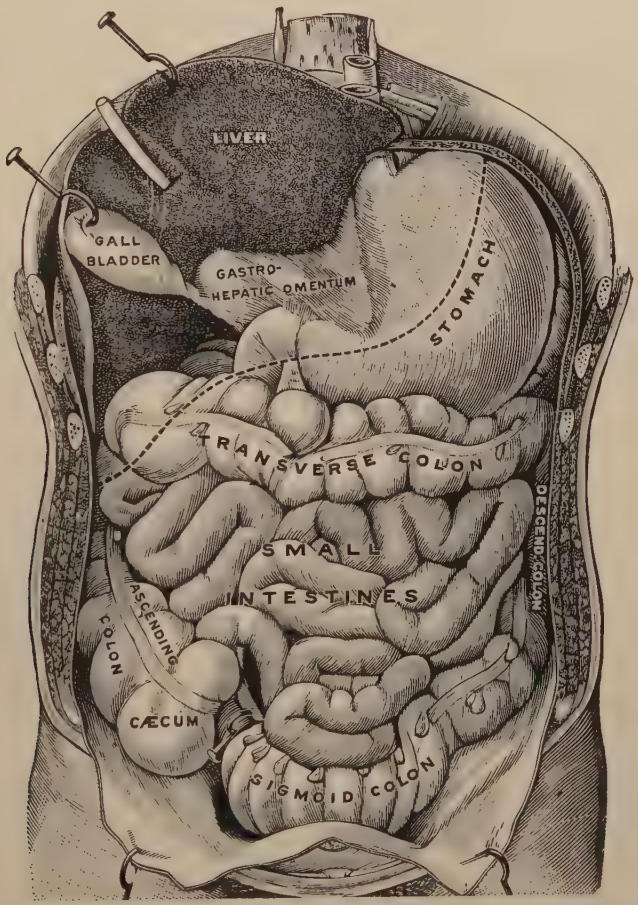


FIG. 192.—THE STOMACH AND INTESTINES, FRONT VIEW, THE GREAT OMENTUM HAVING BEEN REMOVED, AND THE LIVER TURNED UP AND TO THE RIGHT. The dotted line shows the normal position of the anterior border of the liver. (Gerrish.)

unstriped muscular tissue: an outer, longitudinal layer; a middle or circular layer; and an inner, less well-developed, oblique layer. This arrangement facilitates the peristaltic action of the stomach by which it presses upon the food and moves it back and forth.

(3) The **submucous** coat consists of loose areolar tissue connecting the muscular and mucous coats. It carries nerves and vessels.

(4) The **mucous** coat is very soft and thick, the thickness being mainly due to the fact that it is densely packed with small glands. It is covered with columnar epithelium, and in its undistended condition is thrown into folds or rugæ. The surface is honeycombed by tiny, shallow pits, into which the ducts or mouths of the glands open.

Gastric glands.—The gastric glands are of three varieties, (1) cardiac; (2) true gastric or peptic; and (3) pyloric.

(1) Cardiac glands are mainly simple tubular glands found about the cardiac or esophageal orifice. They secrete mucin.

(2) True gastric or peptic glands are simple tubular glands[4] distributed throughout the fundus and intermediate region of the stomach and may even be found at the pyorlus. These glands are lined by epithelial cells of which there are two varieties. (*a*) One variety of cell is found lining the lumen of the tube. These are called chief or central cells and secrete pepsinogen. (*b*) A second variety called parietal or oxyntic cells are found behind the chief cells, where they do not come in contact with the lumen. These cells secrete acid, and pepsinogen in the presence of acid is converted into pepsin.

Fig. 193.—Gastric glands showing at 1, chief or central cells; 2, the parietal cells; 3, lumen and 4 connective tissue surrounding gland.

(3) Pyloric glands are branched tubular glands found most plentifully about the pylorus. They secrete pepsinogen and mucin.

The combined secretion of these glands forms the gastric fluid.

Some of the cells of the mucous membrane secrete a hormone known as gastrin, which is carried by the blood to the peptic and pyloric glands, and stimulates them to secretory activity.

Nerves and blood-vessels.—The stomach is supplied with nerves from the sympathetic system, and also with afferent and efferent branches from the vagus nerve. Stimulation of the vagus fibers increases secretion and peristalsis. Stimulation of the sym-

[4] Also called fundus or oxyntic.

pathetic fibers has just the opposite effect, *i.e.*, inhibits secretion and peristalsis. The blood-vessels are derived from the three divisions of the celiac, *i.e.*, the left gastric, and branches of the hepatic and splenic.

Functions.—The functions of the stomach are (1) to connect the esophagus with the intestine. (2) To receive the food in relatively large quantities, say about three times a day, hold it while it undergoes certain mechanical and chemical changes,[5] then pass it on to the intestine in small portions at frequent intervals. (3) To secrete mucin and gastric fluid.

THE SMALL, OR THIN, INTESTINE

The small intestine extends from the stomach (pyloric valve) above to the large intestine (ileocecal or colic valve) below. It is a convoluted tube about twenty-three feet (7 m.) in length, and fills the greater part of the front abdominal cavity. Its diameter at the beginning is about one and one-half inches (3.8 cm.), but it gradually diminishes in size and is hardly an inch in diameter at its lower end. The small intestine is divided by anatomists into three portions:—the duodenum, jejunum, and ileum,—but they are all continuous and show only slight variations.

The duodenum.—The duodenum is twelve fingers' breadth in length (ten inches or 25 cm.), and is the shortest and broadest part of the small intestine. It extends from the pyloric end of the stomach to the jejunum.

Beginning at the pylorus, the duodenum at first passes upward and backward to the under surface of the liver; it then makes a complete bend and passes downward in front of the kidney; it again turns in a right angle direction to the left and passes horizontally across the front of the vertebral column. This third portion of the duodenum lies retroperitoneally, so that only its anterior aspect is covered by peritoneum. The small intestine now passes forward so as to leave the posterior abdominal wall, and becomes completely invested by peritoneum and has a true mesentery. The point at which it becomes completely invested by peritoneum marks the termination of the duodenum and the beginning of the jejunum. The ducts from the pancreas and liver open into the duodenum about four or five inches (10 cm.—12.5 cm.) below the stomach.

The jejunum.—The jejunum or empty intestine, so called because it is always found empty after death, constitutes about

[5] For discussion of mechanical and chemical changes see pages 371 and 372.

two-fifths of the remainder, or seven and a half feet (2.2 m.), of the small intestine, and extends from the duodenum to the ileum.

The ileum.—The ileum, or twisted intestine, so called from its numerous coils, constitutes the remainder of the small intestine, and extends from the jejunum to the large intestine, which it joins at a right angle. The orifice is guarded by a sphincter muscle which acts as a valve, and prevents the return of material that has been discharged into the large bowel. This is known as the ileocecal sphincter or colic valve.

Fig. 194.—Portion of Small Intestine Laid Open to Show Circular Folds (valvulæ conniventes). Not highly enough magnified to show villi on valvulæ conniventes. (Collins.)

There is no definite landmark to determine the point at which the jejunum ceases and the ileum begins, although the mucous membrane of the one differs somewhat from the mucous membrane of the other; the change is a gradual transition, and one structure shades off into the other. The lengths in feet as given are arbitrary, but those usually accepted.

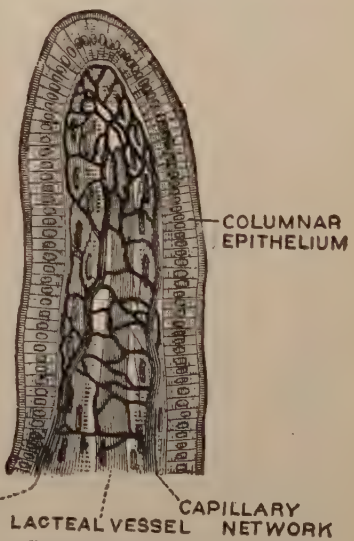


Fig. 195.—An Intestinal Villus. (Highly magnified.)

Coats of the small intestine.—The small intestine has four coats, which correspond in character and arrangement with those of the stomach.

(1) The **serous** coat furnished by the peritoneum forms an almost complete covering for the whole tube except for part of the duodenum.

(2) The **muscular** coat of the small intestine has only two layers: an outer, thinner and longitudinal: and an inner, thicker

and circular. This arrangement aids the peristaltic action of the intestine.

(3) The **submucous,** or areolar coat connects the muscular and mucous coats.

(4) The **mucous** coat is thick and very vascular.

Circular folds.—About one or two inches beyond the pylorus the mucous and submucous coats of the small intestine are arranged in circular folds (valvulæ conniventes or plicæ circulares). Some of these folds extend all the way around the circumference of the intestine; others extend only one-half or one-third of the way. Unlike the rugæ of the stomach, the circular folds do not disappear when the intestine is distended. About the middle of

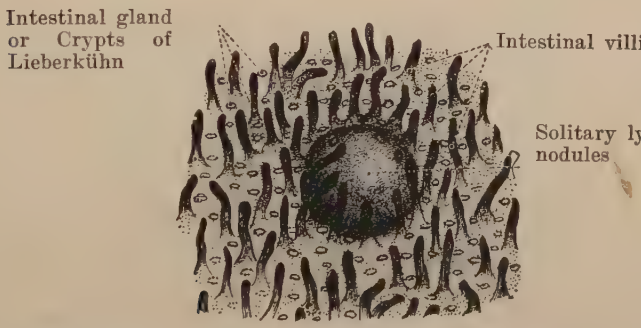


FIG. 196.—MUCOUS MEMBRANE OF THE ILEUM, SHOWING VILLI, A SOLITARY LYMPH-NODULE AND THE MOUTHS OF INTESTINAL GLANDS. (Toldt.)

the jejunum they begin to decrease in size, and in the lower part of the ileum they almost entirely disappear. The purpose of these folds is: (1) to prevent the food from passing through the intestines too quickly, and (2) to present a greater surface for the absorption of digested food.

Villi.—Throughout the whole length of the small intestine the mucous membrane presents a velvety appearance due to minute finger-like projections called villi. Each villus consists of a central lymph-channel called a lacteal, surrounded by a network of blood capillaries, held together by lymphoid tissue. This in turn is surrounded by a layer of columnar cells. After the food has been digested it passes into the capillaries and lacteals of the villi, so that this arrangement increases the surface for absorption.

Glands and nodes of the small intestine.—Besides these projections formed for absorption the mucous membrane is

thickly studded with secretory glands and nodes. These are known as—

1. Intestinal glands or crypts of Lieberkuhn.
2. Duodenal or Brunner's glands.
3. Lymph-nodules { (*a*) Solitary lymph-nodules. (*b*) Aggregated lymph-nodules.

(1) *Intestinal glands.*—These glands are found over every part of the surface of the small intestine.[6] They are simply tubular depressions in the mucous membrane, lined with columnar epithelium.

(2) *Duodenal glands.*—These are compound glands found in the submucous tissue of the duodenum. The intestinal glands and the duodenal glands secrete the intestinal digestive fluid which is named the succus entericus.

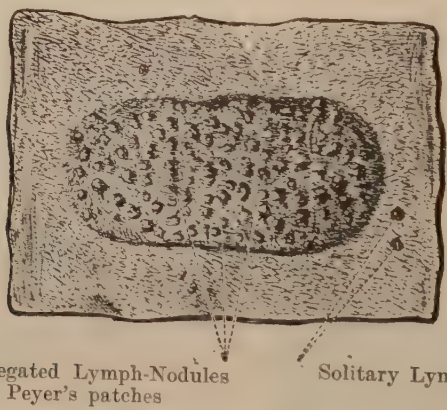


FIG. 197.—AGGREGATED LYMPH-NODULE. (Peyer's Patch.) (Toldt.)

(3) *Lymph-nodules.*—(*a*) Closely connected with the lymphatic vessels in the walls of the intestines are small, rounded bodies of the size of a small pin's head, called *solitary lymph-nodules.* They are most numerous in the lower part of the ileum and consist of a rounded mass of fine lymphoid tissue, the meshes of which are crowded with leucocytes. Into this mass of tissue one or more small arteries enter and form a capillary network, from which the blood is carried away by one or more small veins. Surrounding the mass are lymph channels which are continuous with the lymphatic vessels in the tissue below.

(*b*) *Aggregated lymph-nodules.*—They are simply collections of lymph-nodules, commonly called Peyer's patches. These patches are circular or oval in shape, from ten to thirty in number

[6] Found in large intestine, also see page 348.

and vary in length from about one inch to four inches (2.5 to 10 cm.). They are largest and most numerous in the ileum. In the lower part of the jejunum they are small and few in number. They are occasionally seen in the duodenum. These Peyer's patches are the seat of local inflammation and ulceration in typhoid fever.

Nerves and blood-vessels.—The vagi nerves supply sensory, and motor fibers to the small intestine. Autonomic nerves are derived from the plexuses around the superior mesenteric artery. From this source they run to Auerbach's plexus of nerves and ganglia situated between the circulatory and longitudinal muscular fibers. Branches from this plexus are distributed to the muscular coats, and from these branches a secondary plexus, Meissner's plexus, is derived. This plexus is in the submucous coat and sends fibers to the mucous membrane. The arteries supplying the small intestine are branches of the hepatic; and branches of the superior mesenteric.

Function.—It is in the small intestine that the greatest amount of digestion and absorption takes place. It receives the bile from the liver and the pancreatic fluid from the pancreas. The glands of the small intestine secrete the succus entericus. The circular folds delay the food so that it is more thoroughly subjected to the action of these digestive fluids; and being covered with villi they increase the surface for absorption. Some of the cells of the mucous membrane (particularly in the duodenum) secrete a substance known as prosecretin. When the acid chyme enters the intestine, prosecretin is changed to secretin, and carried by the blood to the liver, pancreas and all parts of the intestine, stimulating them to secretory activity.

THE LARGE, OR THICK, INTESTINE

The largeness of the next division of the alimentary canal is in its width, not in its length; for it is only about five feet (1.5 m.) long, but is wider than the small intestine, being about two and one-half inches (6.3 cm.) in its broadest part. It extends from the ileum to the anus. It is divided into four parts: the cecum with the vermiform appendix, colon, rectum and anal canal.

The cecum.—The cecum (*cæcus*, blind) is a large blind pouch at the commencement of the large intestine. The small intestine opens into the side wall of the large intestine about two and a half inches (6.3 cm.) above the commencement of the large intes-

tine. This two and one-half inches of large intestine forms a cul-de-sac called the cecum. The opening from the ileum into the large intestine is provided with two large projecting lips of mucous membrane which allow the passage of material into the large intestine, but effectually prevent the passage of material in the opposite direction. These mucous folds form what is known as the ileocecal or colic valve.

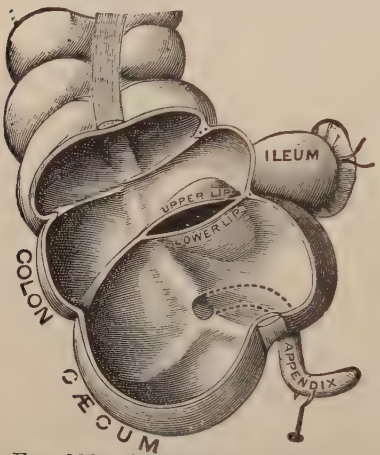


FIG. 198.—CAVITY OF THE CECUM, ITS FRONT WALL HAVING BEEN CUT AWAY. The valve of the colon (colic) and the opening of the appendix are shown. (Gerrish.)

The **vermiform appendix** is a narrow, wormlike tube about the diameter of an ordinary lead pencil, and from less than one to eight inches (2 to 20 cm.) long. It is attached to the lower end of the cecum, but its directions and relations are very variable. In a general way it may be said to be located in the right iliac region. The function of the appendix is not known. It is most fully developed in the young adult, and at this time is subject to inflammatory and gangrenous conditions commonly called appendicitis. The reasons for this are its structure does not allow of ready drainage, its blood-supply is limited, and its circulation is easily checked, because the vessels anastomose to a very limited extent, in youth it contains a considerable amount of lymphoid tissue which unlike the lymph-nodes is specially prone to bacterial invasion.

The colon.—The colon, though one continuous tube, is subdivided into the *ascending*, *transverse* or *mesial*, *descending*, and the *sigmoid colon*. The ascending portion ascends on the right side of the abdomen until it reaches the under surface of the liver, where it bends abruptly to the left (right colic or hepatic flexure), and is continued across the abdomen as the transverse colon until, reaching the left side, it curves beneath the lower end of the spleen (left colic or splenic flexure), and passes downward as the descending colon. Reaching the left iliac region on a level with the margin of the crest of the ileum, it makes a curve

like the letter S,—hence its name of sigmoid,—and finally ends in the rectum. (See Fig. 192.)

The rectum.—The rectum is from six to eight inches (15 to 20 cm.) long; from its origin at the third sacral vertebra it descends along the curve of the sacrum and the cocyx, and finally bends sharply backward into the anal canal.

The anal canal.—The anal canal is the terminal portion of the large intestine, and is about an inch or an inch and one-half (2.5 to 3.8 cm.) in length. The external aperture is called the anus. The anus is guarded by an internal sphincter muscle of the involuntary type,[7] and an external sphincter that is voluntary, but both are supplied with nerves from the central nervous system. Consequently it is kept closed except during defecation.

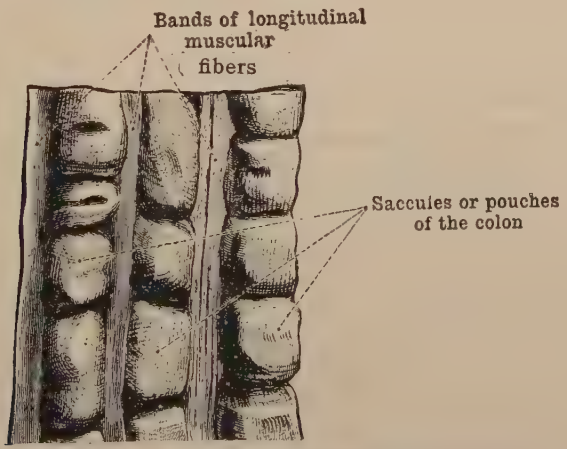


FIG. 199.—THE MUSCULAR COAT, OF THE OPENED LARGE INTESTINE, SHOWING THE LONGITUDINAL FIBERS. (Toldt.)

Coats of the large intestine.—The large intestine has the usual four coats except in some parts where the serous coat only partially covers it, and the rectum, where the serous coat is lacking. The **muscular** coat consists of two layers of fibers, one arranged longitudinally and the other circularly. Beginning at the appendix, the longitudinal fibers are arranged in three ribbon-like bands, which extend the whole length of the colon to the rectum, and these bands being shorter than the rest of the tube, the walls are puckered between them. The third coat consists of **submucous areolar tissue,** and the fourth or inner coat consists of **mucous membrane.** The mucous coat possesses no villi and no

[7] It is really a thickening of the circular fibers of the muscular coat.

circular folds. It contains intestinal glands and solitary lymph-nodules which closely resemble those of the small intestine.

Nerves and blood-vessels.—The nerves are derived from plexuses around the superior and inferior mesenteric arteries. The arteries are derived from the colic and sigmoid branches of the mesenteric (superior and inferior) arteries.

Functions.—The functions of the large intestine are three. The process of digestion is continued due to the digestive fluids with which the food becomes mixed in the small intestine, the process of absorption is continued, and the waste products are removed from the body.

ACCESSORY ORGANS OF DIGESTION

The accessory organs of digestion are: (1) the salivary glands, (2) the tongue, (3) the teeth, (4) the pancreas, and (5) the liver. The first three have been described.

Pancreas.—The pancreas lies in front of the first and second lumbar vertebræ and behind the stomach. Its average weight is between two and three ounces (60 to 90 grams), it is about five inches (12.5 cm.) long, and about two inches (5 cm.) wide. In shape it somewhat resembles a hammer, and is divided into head body, and tail. The right end, or head, is thicker and fills the curve of the duodenum, to which it is firmly attached. The left, free end, is the tail, and reaches to the spleen. The intervening portion is the body.

Structure of the pancreas.—It is a compound racemose gland composed of lobules. Each lobule consists of one of the branches of the main duct which terminates in a cluster of saccules that are grape-like in appearance. The lobules are joined together by connective tissue to form lobes, and the lobes, united in the same manner, form the gland. The small ducts from each lobule open into one main duct about the size of a goose-quill, which runs lengthwise through the gland, from the tail to the head. This is known as the pancreatic duct, or duct of Wirsung. The pancreatic and common bile duct usually unite and enter by means of a common opening into the duodenum about three inches (7.5 cm.) below the pylorus. The short tube formed by the union of the two ducts is dilated into an ampulla, called the *ampulla of Vater*. Sometimes the pancreatic duct and the common bile duct open separately into the duodenum, and there is frequently an accessory duct (duct of Santorini) which opens into the duodenum about an inch above the orifice of the main duct. (See Fig. 200.)

Islands of Langerhans.—Scattered throughout the pancreas are collections of cells known as the islands of Langerhans. They are surrounded by a rich capillary network. Their function is to furnish the internal secretion of the pancreas.

Function.—Two secretions are formed in the pancreas. (1) The pancreatic fluid, one of the most important of the digestive fluids, is an external secretion and is poured into the duodenum during intestinal digestion. (2) The secretion formed by the islands of Langerhans is an internal secretion from which insulin has been extracted. It is absorbed by the blood and carried to

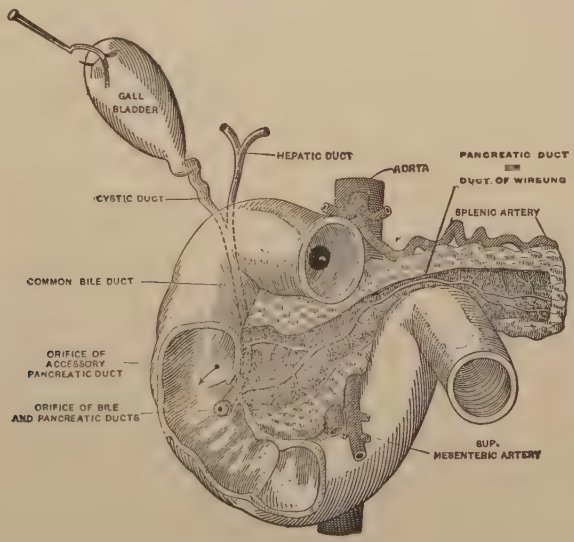


FIG. 200.—DUCTS OF THE PANCREAS. Part of the front of the duodenum is cut away. (Gerrish.)

the tissues. This internal secretion aids in the oxidation of glucose by the tissue cells.

THE LIVER

The liver (hepar) is the largest gland in the body, weighing ordinarily from forty-two to fifty-six ounces (1.2–1.6 kilogram). The upper convex surface fits closely into the under surface of the diaphragm. The under concave surface of the organ fits over the right kidney, the upper portion of the ascending colon, and the pyloric end of the stomach.

Ligaments.—The liver is connected to the under surface of the diaphragm, and the anterior walls of the abdomen by five ligaments, four of which the falciform, the coronary, and the two lateral are formed by folds of peritoneum. The fifth, or round ligament, is a fibrous cord resulting from the atrophy of the umbilical vein of intrauterine life.

Fissures.—The liver is divided by four fissures[8] into four lobes.

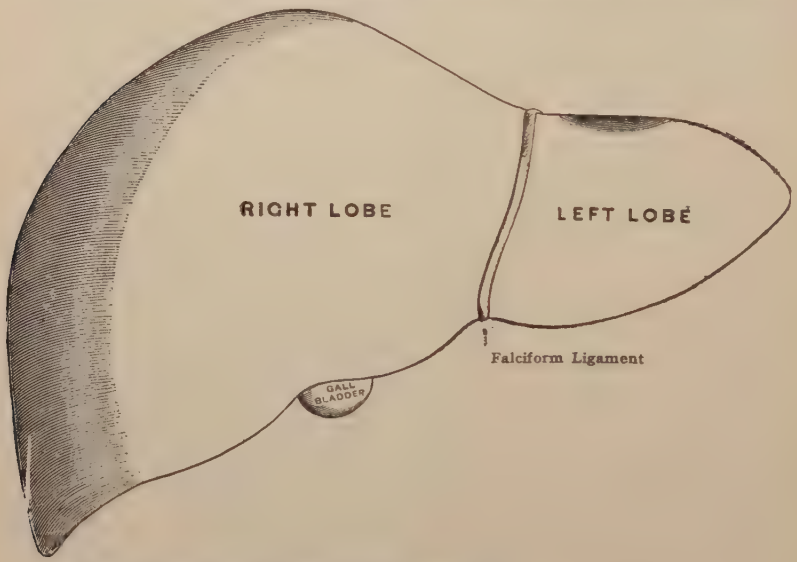


FIG. 201.—THE LIVER. Front view. The liver measures eight to nine inches (20 to 22.5 cm.) from side to side, four to five inches (10 to 12.5 cm.) from front to back, and six to seven inches (15 to 17.5 cm.) from above downward in its thickest part. (Gerrish.)

The important fissures are (1) the left sagittal, (2) the portal, or transverse, which is the gateway for vessels, ducts, and nerves to enter and leave the liver, and (3) the gall-bladder fissure, which supports the gall-bladder and (4) the fissure for the inferior vena cava

Lobes.—The liver is divided into four lobes:—

1. Right (largest lobe).
2. Left (smaller and wedge-shaped).
3. Quadrate (square).
4. Caudate (tail-like).

Vessels.—The liver has five sets of vessels:—

1. Branches of portal tube.
2. Hepatic veins.
3. Bile ducts.
4. Branches of hepatic artery.
5. Lymphatics.

[8] Also called fossæ.

Anatomy of liver.—The liver may be regarded as made up of many minute livers called lobules. Each **lobule** is an irregular body from one-twentieth to one-tenth of an inch (1–2.5 mm.) in diameter, composed of a multitude of hepatic cells held together by areolar tissue in which ramify capillaries derived from the portal vein and the hepatic artery, nerves, lymphatics and hepatic ducts. Thus each lobule has all the essentials of a gland; (1) blood-vessels in close connection with secretory cells, (2) cells which are capable of forming a secretion, and (3) ducts by which the secretion is carried away.

The portal tube.—The portal tube brings to the liver venous blood from the stomach, spleen, pancreas, and intestines. After entering the liver, it divides into a vast number of branches which form a plexus, the interlobular plexus in the spaces between the

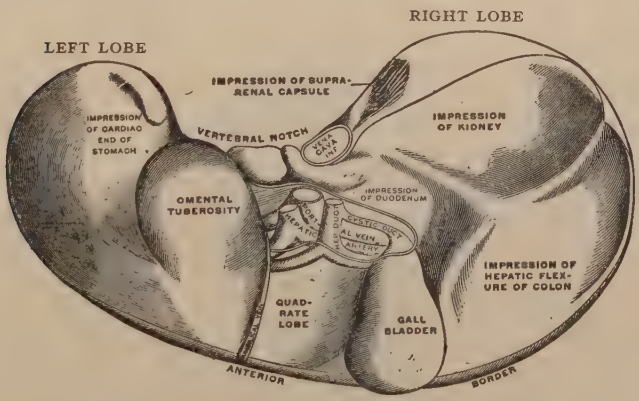


FIG. 202.—THE LIVER. Lower surface. (Gerrish.)

lobules. From this plexus the blood is carried into the lobule by fine branches which converge toward the center. The walls of these small vessels are incomplete, so that the blood containing the raw material for the manufacture of bile is brought in direct contact with each cell. These channels are termed *sinusoids*, and at the center of the lobule they empty the blood into the intralobular vein. The intralobular veins from a number of lobules empty into a much larger vein upon whose surface a vast number of lobules rest, and therefore the name **sublobular**

(under the lobule) is given to these veins. They empty into still larger veins, the **hepatic,** which converge to form three large trunks and empty into the **inferior vena cava,** which is embedded in the posterior surface of the gland.

The bile-ducts.—The surfaces of the hepatic cells are grooved, and the grooves on two adjacent cells fit together and form a channel or canaliculus into which the bile is poured as soon as it is formed by the cells. These canaliculi form a network between and around the cells as intricate as the network of blood-vessels. They are called intralobular ducts, and empty into larger ducts called interlobular. These unite and form larger and larger ducts until two main ducts, one from the right and one from the left side of the liver, unite in the portal fissure and form the *hepatic duct.*

The **hepatic duct** passes downward and to the right for about two inches (5 cm.) and then joins at an acute angle the duct from

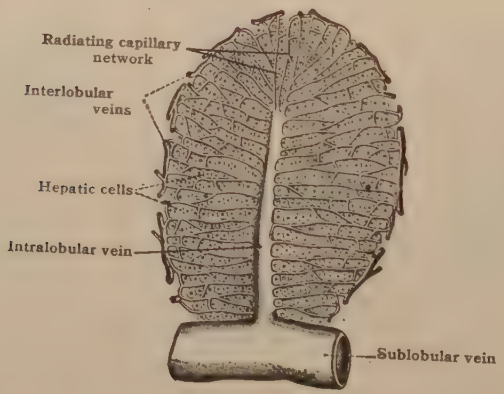


FIG. 203.—DIAGRAMMATIC REPRESENTATION OF A LONGITUDINALLY DIVIDED HEPATIC LOBULE. (Toldt.)

the gall-bladder, termed the *cystic duct.* The hepatic and cystic ducts together form the *common bile-duct* (*ductus communis choledochus*), which passes downward for about three inches (7.5 cm.) and enters the duodenum about three inches (7.5 cm.) below the pylorus. This orifice usually serves as a common opening for both the common bile and the pancreatic duct. It is very small and is guarded by a sphincter muscle which keeps it closed except during digestion. (See Fig. 200.)

Hepatic artery.—We must remember that the blood brought to the liver by the portal tube is venous blood and is not intended for purposes of nourishment of the liver itself, hence arterial blood is furnished by the *hepatic artery*. It enters the liver with the portal tube, divides and subdivides in the same manner as the portal tubes, thus forming another network between the lobules, and in the lobules between the cells. The capillaries from the portal tube and the hepatic artery are separate and distinct until, near the center of each lobule, they unite, and all the blood supplied to the liver by the portal tube and hepatic artery is carried away from it by the hepatic veins which empty into the inferior vena cava.

Lymphatics.—There is a superficial and a deep set. They begin in irregular spaces in the lobules, form networks around

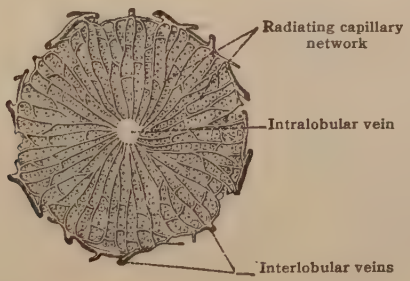


FIG. 204.—DIAGRAMMATIC REPRESENTATION OF A TRANSVERSELY DIVIDED HEPATIC LOBULE. (Toldt.)

the lobules, and run always from the center outward. They drain off waste products and unconsumed nutritious substances.

Glisson's capsule.—The whole liver is invested in an outer capsule of areolar connective tissue, which is reflected inward at the portal fissure and encloses the vessels and ducts passing through this opening. With the exception of a few small areas, the liver is enclosed in a serous tunic derived from the peritoneum.

Nerves.—Nerves are derived from the left vagus and the celiac plexus.[9]

Functions.—The liver has many important functions:—

[9] See page 164.

Bile production.—The cells of the liver manufacture bile from the blood brought to them by the portal tube. The function of bile is considered in the next chapter.

Glycogenic.—The cells of the liver take from the blood brought to them by the portal tube a substance called glucose, which is derived from the carbohydrates of our food. This is stored in the liver in the form of glycogen until such time as the body needs more glucose than the food furnishes. When such demand is made, the liver cells reconvert the glycogen into glucose and pour it into the circulation.

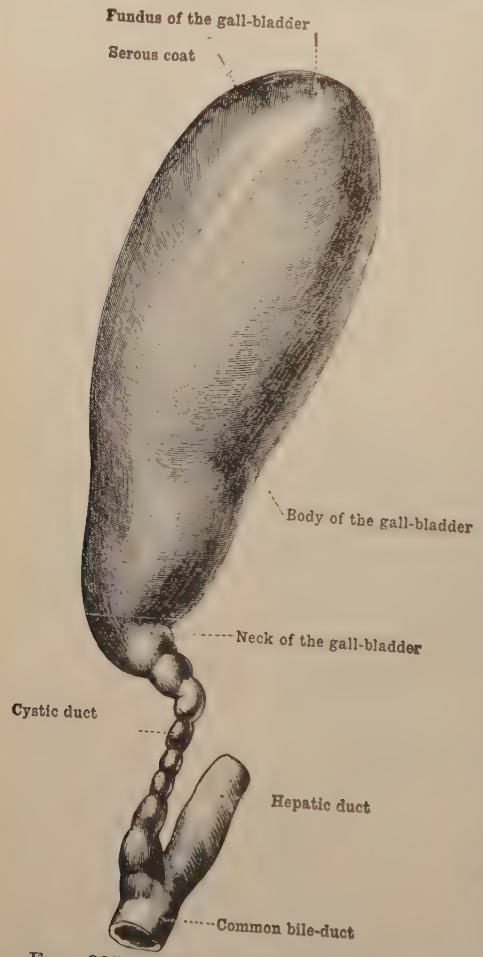


FIG. 205.—THE GALL-BLADDER, MODERATELY DISTENDED, WITH THE CYSTIC DUCT AND THE JUNCTION OF THE LATTER WITH THE HEPATIC DUCT TO FORM THE COMMON BILE-DUCT. (Toldt.)

Secretory.—It is assumed that the liver furnishes an internal secretion which helps to regulate the changing of glucose to glycogen and then to glucose again.

Protective.—Its protective function is exercised in three ways: (*a*) Many of the end-products of protein digestion cannot be eliminated until they are acted upon by the liver, and changed into other substances which the kidneys can eliminate, *e.g.*, urea is made from some of these end-products brought to the liver by the blood. (*b*) It finishes the disintegration of the worn out erythrocytes, which process is commenced in the spleen. (*c*) It plays an important part in the

clotting of the blood, because it gives rise to antithrombin.

Heat-formation.—The liver produces heat.

The gall-bladder.—The gall-bladder is a pear-shaped sac lodged in the gall-bladder fissure on the under surface of the liver, where it is held in place by connective tissue. It is about three to four inches (7 to 10 cm.) long, one inch (2.5 cm.) wide, and holds about nine drachms (36 cc.). It is composed of three coats: (1) the inner one is mucous membrane, (2) the middle one is muscular and fibrous tissue, and (3) the outer one is serous membrane derived from the peritoneum. It is only occasionally that the peritoneum covers more than the under surface of the organ.

Function.—The gall-bladder serves as a reservoir for the bile. In the intervals between digestion, *i.e.*, when the duodenum is empty, the sphincter guarding the bile-duct is contracted and the bile is held in the gall-bladder. It is thought that the acid chyme entering the duodenum relaxes the sphincter, and the gall-bladder contracts and forces out its contents, which pour into the duodenum.

SUMMARY

Digestion.—Digestion is dependent on the proper functioning of certain organs that are grouped together and called the digestive system.

- **Digestive System**
  - **Alimentary canal**
    - Mouth.
    - Pharynx.
    - Esophagus, or gullet.
    - Stomach.
    - Small or thin intestine
      - Duodenum.
      - Jejunum.
      - Ileum.
    - Large or thick intestine
      - Cecum.
      - Colon
        - Ascending.
        - Transverse.
        - Descending.
        - Sigmoid.
      - Rectum.
      - Anal canal.
  - **Accessory organs**
    - Salivary glands.
    - Tongue.
    - Teeth.
    - Pancreas.
    - Liver.
- **Alimentary Canal**
  - Continuous tube from mouth to anus.
  - About 30 ft. long
    - Esophagus—4 coats
      - Mucous.
      - Submucous or areolar.
      - Muscular.
      - Fibrous.
  - From diaphragm to rectum—4 coats
    - Mucous.
    - Submucous or areolar.
    - Muscular.
    - Serous derived from peritoneum.

Mouth, or Buccal Cavity

- Above—palate
  1. Hard palate.
  2. Soft palate—uvula, pillars of the fauces, and tonsils.
- Below—tongue.
- Front—lips.
- Sides—cheeks.
- Back—pharynx.
- Contains
  - Tonsils.
  - Tongue.
  - Salivary glands.
  - Teeth.

Tonsils

- Collection of lymph-nodules occupy triangular space between pillars of the fauces on either side of throat.
- **Function**
  - Function imperfectly understood.
  - May act as filters and prevent entrance of micro-organisms.

Tongue

- Special organ of sense of taste.
- Assists in digestion
  1. Stimulates secretion of digestive fluids.
  2. Assists in swallowing.
  3. Secretes mucin.

Salivary Glands

- Parotid—just under and in front of ear.
- Submaxillary, Sublingual—Below the jaw and under the tongue.
- **Function**—Form a secretion, that mixed with the secretion of the glandular cells of the mouth is called saliva.
- **Nerves**
  - Cranial
    - Facial.
    - Glossopharyngeal.
  - Autonomic system.

Teeth

- Contained in sockets of alveolar processes of maxillæ and mandible.
- **Gums**—cover processes and extend into sockets.
- **Sockets**—lined with periosteum
  - Attaches teeth to sockets.
  - Source of nourishment.
- 3 portions
  - *Root*—one or more fangs contained in socket.
  - *Crown*—projects beyond level of gums.
  - *Neck*—portion between root and crown.
- Composed of three substances developed from epithelium
  - *Dentin*
    - Gives shape.
    - Encloses pulp cavity which contains nerves and blood-vessels, that enter by canal from root.
  - *Enamel*—Caps the crown.
  - *Cement*—Covers the root.
- 2 sets
  1. Temporary—6 months to 2 yrs.
     - Incisors 8
     - Canines 4
     - Molars 8

     } 20.

     Begin to develop about the sixth week of intrauterine life.
  2. Permanent—6½ yrs. to 25 yrs. of age
     - Incisors 8
     - Canines 4
     - Premolars 8
     - Molars 12

     } 32.

     With the exception of the second and third, molars begin to develop about the sixteenth week of intrauterine life.
- **Function**—To assist in the process of mastication.

Pharynx
- Cone-shaped tube, 5 inches long, between mouth and esophagus.
- Muscular, lined with mucous membrane.
- 7 apertures:
  - 2 posterior nares.
  - 2 Eustachian tubes.
  - 1 fauces.
  - 1 larynx.
  - 1 esophagus.
- **Function**—To receive the food from the mouth and pass it to the esophagus.

Esophagus, or Gullet
- Tube—9 to 10 inches long. Extends from pharynx to stomach.
- 4 coats:
  1. External or fibrous.
  2. Muscular
     - Internal circular layer.
     - External longitudinal layer.
  3. Submucous or areolar.
  4. Internal or mucous.
- **Function**
  1. Connects the pharynx with the stomach.
  2. Receives the food and passes it on to stomach.

Stomach, or Gaster
- Dilated portion of canal, size and shape vary.
- Oblique position in epigastric and left hypochondriac regions under the diaphragm.
- Openings:
  - Cardiac orifice—connects with esophagus.
  - Pyloric orifice—connects with duodenum.
  - Guarded by ring-like muscles known as sphincters.
- Curvatures:
  - Lesser curvature—concave border.
  - Greater curvature—convex border.
- Parts:
  - Fundus—blind end to the left of the heart.
  - Intermediate region—between fundus and pyloric extremity.
  - Pyloric extremity—under the liver.
- 4 coats:
  1. Outer—serous—peritoneum.
  2. Muscular
     1. Longitudinal layer.
     2. Circular layer.
     3. Oblique layer.
  3. Submucous—vascular.
  4. Mucous—rugæ.
- Glands:
  - Cardiac—Secrete mucin.
  - Peptic
    - Chief or central cells secrete pepsinogen;
    - parietal or oxyntic cells secrete acid.
  - Pyloric—Secrete pepsinogen and mucin.
- Nerves:
  - Sympathetic system.
  - Vagi nerves.
- Blood-vessels from three divisions of the celiac.
- **Functions**
  1. Connects the esophagus with the intestine.
  2. Receives food in relatively large quantities about 3 times a day, holds it while it undergoes mechanical and chemical changes, then passes it on in small portions, at frequent intervals.
  3. Secretes mucin and gastric fluid.

Small, or Thin, Intestine
- Convoluted tube extends from stomach to ileocecal valve. Twenty-three feet, coiled up in abdominal cavity.
- 3 divisions:
  - Duodenum.
  - Jejunum.
  - Ileum.

Small, or Thin, Intestine

- **4 coats**
  - 1. Serous from peritoneum, called mesentery.
  - 2. Muscular
    - Longitudinal layer.
    - Circular layer.
  - 3. Submucous—Connects the muscular and mucous coats.
  - 4. Mucous
    - Circular folds.
    - Villi—contain lacteals.
- **Glands and nodes**
  - Intestinal glands
  - Duodenal or Brunner's — Secrete intestinal fluid.
  - Lymph-nodules
    - Solitary.
    - Aggregated lymph-nodules called Peyer's patches.
- **Nerves**
  - Vagi supply sensory and motor fibers.
  - Autonomic nerves derived from plexuses around superior mesenteric artery.
- **Blood-vessels**
  - Branches of the hepatic.
  - Branches of the superior mesenteric.
- **Function**
  - Digestion.
  - Receives bile from liver, pancreatic fluid from pancreas.
  - Secretion of succus entericus. Some cells secrete prosecretin.
  - Absorption.

Large, or Thick, Intestine

- Largeness in width, not in length.
- Length, 5 ft.; width, 2½ in. to 1½ in.
- Extends from ileum to anus.
- **3 divisions**
  - Cecum, with vermiform appendix.
  - Colon
    - Ascending.
    - Transverse.
    - Descending.
    - Sigmoid.
  - Rectum.
  - Anal canal—anus
    - Internal sphincter.
    - External sphincter.
- **4 coats**
  - 1. Serous, except that in some parts it is only a partial covering, and at rectum it is wanting.
  - 2. Muscular
    - Longitudinal layer — Arranged in three ribbon-like bands that begin at appendix, and extend to rectum.
    - Circular layer.
  - 3. Submucous.
  - 4. Mucous
    - No villi.
    - No circular folds.
    - Numerous
      - Intestinal glands.
      - Solitary lymph-nodules.
- Nerves—Derived from plexuses around mesenteric arteries.
- Blood-vessels—Derived from mesenteric arteries.
- **Function**
  - Continuance of digestion and absorption.
  - Elimination of waste.

Pancreas

- In front of first and second lumbar vertebræ, behind stomach.
- Hammer shape
  - Head attached to duodenum.
  - Body in front of vertebra.
  - Tail reaches to spleen.
- Size
  - About five inches long.
  - About two inches wide.
- Average weight—two to three ounces.
- Structure
  - Compound gland—sacculated ends of tubules form lobules.
  - Lobules held together by connective tissue form lobes.
  - Lobes form gland.
  - Duct from each lobule empties into pancreatic duct, also called duct of Wirsung.
  - Scattered throughout pancreas are islands of Langerhans.
- Function
  1. Secretes pancreatic fluid—digestive fluid.
  2. Forms an internal secretion—aids in oxidation of glucose.

Liver

- Largest gland in body.
- Location
  - Right hypochondriac.
  - Epigastric.
  - Left hypochondriac.
- Convex above—fits under diaphragm.
- Concave below—fits over right kidney, ascending colon, and pyloric end of stomach.
- Five ligaments
  1. Suspensory, broad, or falciform — Formed by folds of peritoneum.
  2. Coronary — Formed by folds of peritoneum.
  3. Right lateral — Formed by folds of peritoneum.
  4. Left lateral — Formed by folds of peritoneum.
  5. Round ligament — Results from atrophy of umbilical vein.
- Four fissures
  1. Left sagittal fissure.
  2. Portal or transverse fissure.
  3. Gall-bladder fissure.
  4. Fissure for inferior vena cava.
- Four lobes
  1. Right (largest lobe).
  2. Left (smaller and wedge-shaped).
  3. Quadrate (square).
  4. Caudate (tail-like).
- Five sets of vessels
  1. Branches of portal tube.
  2. Bile-ducts.
  3. Hepatic veins.
  4. Branches of hepatic artery.
  5. Lymphatics.
- Anatomy of liver
  - Hepatic cells are grouped in lobules.
  - Lobules 1/20—1/10 in. in diameter.
  - Branches of portal tube
    - Interlobular veins (between lobules).
    - Intralobular capillaries (within lobules).
    - Sublobular veins (under lobules).
    - Hepatic veins—exit at portal fissure, empty into inferior vena cava.

Liver

- **Anatomy of liver**
  - Bile ducts
    - Channels between cells (within lobules).
    - Intralobular ducts.
    - Interlobular ducts.
    - Hepatic duct—exit at portal fissure.
  - Branches of hepatic artery
    - Interlobular arteries (between lobules).
    - Intralobular capillaries (within lobules).
    - Course beyond the intralobular capillaries same as that pursued by blood from portal tube.
  - Lymphatics
    - Start in lobules, form network, and run from center to periphery.
    - Act as drain-pipes.
  - Glisson's capsule encloses the whole of the liver.
  - Serous membrane from the peritoneum almost completely covers it.
- **Function**
  1. Bile-production.
  2. Glycogenic—glucose stored as glycogen, changed back to glucose as needed.
  3. Secretory
     - Forms an internal secretion which regulates the changing of glucose to glycogen, and then to glucose again.
  4. Protective
     - (*a*) End-products of digestion changed into substances that can be eliminated.
     - (*b*) Finishes disinetgration of erythrocytes.
     - (*c*) Gives rise to antithrombin.
  5. Heat-formation.

Gall-bladder

- Pear-shaped sac lodged in gall-bladder fissure on under surface of liver.
- Size
  - Three to four inches long.
  - One inch wide.
  - Capacity about nine drachms.
- 3 coats
  1. Mucous membrane.
  2. Fibrous and muscular tissue.
  3. Serous membrane from peritoneum.
- **Function**
  - Serves as a reservoir for bile in intervals between digestion.
  - During digestion—pours bile into duodenum.

CHAPTER XVIII

FOOD.—DIGESTIVE PROCESSES; CHANGES THE FOOD UNDERGOES IN THE MOUTH, STOMACH, SMALL AND LARGE INTESTINES

Man's dependence on plants.—The proteins, carbohydrates and fats found in food are comparable (though not exactly similar) to the proteins, carbohydrates and fats of which human tissues are composed. The cells of green plants that contain chloroplasts utilize the energy of the sun's rays to synthesize carbon dioxide (CO_2) and water (H_2O) which they absorb from the air and soil, into carbohydrates. Using the carbohydrates as a basis, plants manufacture fats and with other salts, especially nitrates, they manufacture proteins. Consequently the life processes in plants are described as constructive, but in man the life processes are first destructive and then constructive. In other words, man cannot synthesize simple substances like carbon dioxide, water, nitrates, etc., into carbohydrates, fats and proteins, but instead splits up the carbohydrates, fats and proteins of food into simpler substances, *i.e.*, simple sugars, glycerin and fatty acids, and amino-acids, and these standard substances the tissue cells can synthesize into the carbohydrates, fats and proteins[1] characteristic of their own tissues. All the processes concerned with the splitting up of carbohydrates, fats and proteins into simple substances are termed **digestive processes,** and take place in the alimentary canal.

FOOD

Definition.—Food is any substance taken into the body, (1) to build tissue, (2) to yield energy, and (3) to regulate body processes.

(1) After birth the material for the growth of the body is derived from our food; also the material to make good the loss resulting from the daily wear and tear of body tissues.

(2) All the body activities require a certain amount of energy; this and all the heat dissipated from the body must be supplied by

[1] The difference in proteins constituting the flesh of human and other animals is comparable to the difference between beef and mutton. Beef and mutton contain the same elementary substances, but they are combined in such a way that the resulting meat is different.

food. The energy in our food is present in the form of potential or latent energy, binding the atoms into molecules, and the molecules into larger masses. The splitting of these complex molecules into smaller and simpler ones releases energy. Food material, over and above what is needed for this purpose, is stored in the body either in the form of fat, or as glycogen in the liver and muscles. This may be regarded as so much reserve fuel which is oxidized when needed to furnish energy.

(3) The results of many experiments show that food contains essential substances called vitamins which regulate nutrition and growth.

Classification of food.—Chemical analysis shows that the elements[2] found in the body are also found in food. Various combinations of these elements give us a great variety of substances which are grouped as follows:

Nutrients or Food Principles	Water.
	Mineral matter or inorganic salts.
	Carbohydrates.
	Fats.
	Proteins.
	Vitamins.

Water.—Water (H_2O) is a compound of hydrogen and oxygen. It enters into the composition of all the tissues, even bone contains about 50 per cent. It supplies fluid for the secretions, and for the chemical reductions occurring in secretion, digestion, and metabolism, also for the transfer of food material, and the elimination of waste. It is an important factor in heat regulation, and next to air is the most necessary principle of life. It constitutes about two-thirds of the body weight (66 per cent), and is likely to constitute five-sixths of the daily income.

Under normal conditions the amount of water in the body remains about the same, even though the intake may vary considerably. If the amount of water is increased, the blood-pressure in the renal vessels is raised and the secretion of urine is stimulated. If the amount of water is decreased, the resulting sensation of thirst is so intolerable that steps are taken to relieve it. With few exceptions it is important to drink a liberal supply of water. It keeps the kidneys active, and favors the removal of toxins and waste matters. It also serves to dilute toxic matter so that there is less danger of irritating the kidneys.

Mineral matter or inorganic salts.—Mineral salts are formed

[2] See page 16.

from the elements iron, calcium, sodium, potassium, magnesium, phosphorus, sulphur, chlorin, iodin, fluorin and silicon. These salts are found in the tissues and fluids of all living things and rank third in quantity among the constituents of the body. They are an essential ingredient of nearly all substances used for food, but a diet that does not contain vegetables and fruit is quite certain to lack some of these salts, calcium and iron especially. Their function has been studied experimentally by varying the diet of animals. Their most important functions are: (1) they are an essential part of all tissues; (2) they regulate osmotic interchanges between the cells and liquids of the body; (3) they reduce the permeability of the walls of the blood-vessels; (4) iron is a constituent of hemoglobin, the oxygen-carrying material of the body; (5) they help to maintain the acid-base equilibrium of the liquids and tissues of the body; (6) they are essential for the tone of visceral muscle. Sodium, potassium and calcium salts are especially important in this respect, and (7) calcium assists in the process of blood-clotting; (8) they are of importance in regulating the irritability of nerves; (9) sodium chlorid (NaCl) furnishes chlorin for the manufacture of the hydrochloric acid of the gastric fluid; and (10) they enter into the composition of the hard parts of bony tissue and give it rigidity.

Phosphorus, calcium, iron, sulphur, etc., enter into organic combinations. Most of the iron of food is in organic combination, and the importance of this is in the fact that the body is able to utilize it, whereas the possibility of synthesizing inorganic iron is seriously questioned.

Fluorin and silicon occur in small quantities in bones and teeth. Their significance is not known, although it is possible that the silicates contribute to the strength and rigidity of bones.

Carbohydrates.—Carbohydrates[3] have a leading place among the solid matters of the diet, but the amount present in the body is rather scant. Under this head we distinguish starches and sugars. They contain but three elements, carbon, hydrogen, and oxygen. The varieties of carbohydrates are: (1) Monosaccharids, having one sugar group $C_6H_{12}O_6$, (2) disaccharids having two sugar groups, and (3) polysaccharids containing an undetermined number of sugar groups.

(1) *Monosaccharids.*—Monosaccharids or simple sugars are one of the standard substances which the tissues can use, and as

[3] Called glucids by Morse, W., Applied Biochemistry, 1925. Published by Saunders Co.

they are freely soluble and of small molecule they are readily absorbed.

Monosaccharids

- Glucose or dextrose, found in fruits, especially the grape, and in the blood. $C_6H_{12}O_6$.
- Fructose or levulose, found with glucose in fruits. $C_6H_{12}O_6$.

} Invert sugar.

(2) *Disaccharids.*—A study of the formulæ of the disaccharids will show that the composition is the same but they are differently named because they give different reactions. Before any of the disaccharids can be utilized in the body they must first be changed either into glucose, or into invert sugar, which consists of a molecule each of glucose and fructose. Only one splitting is necessary as one molecule of a complex sugar plus one molecule of water will form one molecule of glucose and fructose.

Disaccharids

- Sucrose or cane-sugar. $C_{12}H_{22}O_{11}$.
- Lactose or milk-sugar. $C_{12}H_{22}O_{11}$.
- Maltose or malt-sugar. $C_{12}H_{22}O_{11}$.

Disaccharid	Water		Glucose	Fructose
$C_{12}H_{22}O_{11}$	+ H_2O	=	$C_6H_{12}O_6$.	$C_6H_{12}O_6$

Invert Sugar

(3) *Polysaccharids.*—In all of these compounds the composition of the molecule is complex, although the elements are present in the same relative proportion, as shown in the formulæ. The value of n, however, may be very large and is probably different for each polysaccharid, which makes the actual composition of each member of the group different. For instance, n for the starch molecule is large, representing a large number of sugar groups, while for the dextrin molecule it is smaller, so that a single starch molecule in digestion may split into several molecules of dextrin of the same relative composition. In the disaccharids only one splitting is necessary, as each molecule of a complex sugar plus one molecule of water will give two molecules of a simple sugar. As polysaccharids are so complex, they must pass through several stages before they are changed by hydrolysis to simple sugars. Each splitting of the molecule gives substances with simpler composition, though with the same relative proportion of the constituents, and to each is given a special name. Thus as the result of the first splitting we have dextrin of which there are three varieties, *i.e.*, erythrodextrin, achroödextrin, and maltodextrin, each one being produced as a result of the further splitting of the molecules; then maltose, a disaccharid, is yielded, and finally glucose, a monosaccharid or simple sugar. The

number of molecules of simple sugar resulting from the hydrolysis of any polysaccharid would depend upon the value of n.

Polysaccharids	Starch—found in grain, tubers, roots, etc.	$(C_6H_{10}O_5)n$
	Cellulose—outside covering of starch grains, and basis of all woody fibers.	$(C_6H_{10}O_5)n$
	Glycogen—form in which sugar is stored in the liver and muscles.	$(C_6H_{10}O_5)n$
	Dextrin—formed from starch by partial hydrolysis.	$(C_6H_{10}O_5)n$

Cellulose.—This constitutes the groundwork of the fibrous part of plants. The chemical constituents are the same as starch but cellulose is not affected by the digestive juices and undergoes very little digestion in the human alimentary tract. Any digestion that does occur is due to the action of putrefactive bacteria in the large intestine, and the disintegration products are fatty acids.

Glycogen.—Glycogen is a form of animal starch. It is made from glucose in the animal body, especially in the liver, but to some extent in the muscles. Liver is the only meat that contains glycogen; some kinds of fish and oysters also contain it.

Fats.—The word fat is used sometimes in an anatomic and sometimes in a chemical sense. In an anatomic sense the meaning is adipose tissue. In a chemical sense the word fat denotes a compound of carbon, hydrogen and oxygen, having a formula of a certain type. They are not soluble in water, and pass from solid to liquid form at moderate temperatures.[4] The ordinary fats of animal and vegetable food are not simple substances, but are mixtures of simple fats named palmitin, stearin, and olein, which are derived from the fatty acids, palmitic, stearic, and oleic. Each molecule of a simple fat is made from one molecule of glycerin and three molecules of a fatty acid. Both glycerin and fatty acids are compounds of carbon, hydrogen and oxygen, the same elements that constitute carbohydrates, but they are present in very different combinations and proportions; the hydrogen content is relatively high, and the oxygen content low. The reaction between three molecules of fatty acid and one molecule of glycerin in the formation of fat is as follows:—

Acid	+	Base	→	Salt	+	Water
(STEARIC ACID)		(GLYCERIN)		(STEARIN)		(WATER)
$3\,H\,.\,C_{18}H_{35}O_2$	+	$C_3H_5(OH)_3$	→	$C_3H_5(C_{18}H_{35}O_2)_3$	+	$3\,H_2O$

[4] The fats of the human body are fluid at body temperature.

This reaction is comparable to the neutralizing of an acid by a base resulting in a salt and water.

Acid	+	Base	→	Salt	+	Water
HCl	+	NaOH	→	NaCl	+	H_2O

Under the influence of steam, mineral acids, and certain enzymes found in the body, fats split up into the substances of which they are built, *i.e.*, glycerin and fatty acids. Accordingly, the digestion of fats is a reaction in exactly the opposite direction from the one above:

Salt (STEARIN)	+	Water (WATER)	→	Base (GLYCERIN)	+	Acid (STEARIC ACID)
$C_3H_5(C_{18}H_{35}O_2)_3$	+	$3\ H_2O$	→	$C_3H_5(OH)_3$	+	$3\ H.C_{18}H_{35}O_2$

The process of *saponification* is similar to the above, only that instead of water a base is used and the final products are glycerin and soap.

Salt (STEARIN)	+	Base (POTASSIUM HYDROXID)	→	Base (GLYCERIN)	+	Soap (SOAP)
$C_3H_5(C_{18}H_{35}O_2)_3$	+	$3\ KOH$	→	$C_3H_5(OH)_3$	+	$3\ K(C_{18}H_{35}O_2)$.

Complex fats.—Complex fats called lipoids are found in the human body, particularly in nervous tissue. There are three varieties:

(1) Those which have a chemical composition similar to glycerin, *viz.*, cholesterol.

(2) Those which contain both phosphorus and nitrogen. These are called phosphatides, and the best known is lecithin.

(3) Those which are free from phosphorus but contain nitrogen.

Proteins.[5]—Proteins are more complex than either carbohydrates or fats and differ from them in having *nitrogen*, hence they are described as nitrogenous compounds. They consist of carbon, hydrogen, nitrogen, oxygen; sulphur, phosphorus, and other elements may be present.[6] Proteins are difficult to analyze but modern chemists have shown that they are built up of simpler

[5] Called protids by Morse, W., Applied Biochemistry, 1925.

[6] It is quite impossible to convey an adequate impression of the complex fashion in which the five or six elements are combined. Many years ago the following formula was suggested for hemoglobin, the red protein of the blood, which is exceptional in containing iron:

$$C_{758}H_{1203}O_{228}N_{195}FeS_3$$

It is not seriously maintained that these large numbers are precisely correct, but the order of their magnitude is probably typical. From Nutritional Physiology, by Stiles, P. G., published by Saunders Co.

substances called amino-acids. Amino-acids are acids that contain an amino radical (NH_2) instead of a replaceable hydrogen atom.[7] If we take acetic, which is one of the simplest organic acids, we find the formula to be CH_3COOH. If one of the three hydrogen atoms in the CH_3 group is replaced by NH_2 we get a substance which has the formula $CH_2(NH_2)COOH$ and is called amino-acetic acid, glycin or glycocoll. Another organic acid is propionic acid which has the formula C_2H_5COOH; if we replace an atom of hydrogen by the amino group we obtain $C_2H_4(NH_2)COOH$, which is amino-propionic-acid or alanin.

About twenty amino-acids have been described, and are sometimes compared to the letters of the alphabet. Various combinations of letters result in an enormous number of words. In a similar way various combinations of amino-acids result in many different kinds of proteins which give different reactions and are represented by different formulæ. Hence we have milk, meat, fish, egg, cereal, and vegetable proteins, all representing different combinations of the protein alphabet. The legumes—peas, beans, lentils, and peanuts, among vegetables, are especially rich in proteins.

Examples of Protein Constituents of Food

- *Albumin, e.g.*, the white substance seen where egg is heated; the scum that forms on the top of milk when its temperature is raised above 170° F. (76° C.); the white coating that forms on meat when it has been in a hot oven for a short time.
- *Caseinogen, e.g.*, the substance that is formed into a curd when acid or rennet is added to milk, or when milk sours.
- *Gluten, e.g.*, the gummy substance in wheat.
- *Legumin*, a protein substance contained in the legumes.
- *Gelatin*, intercellular substance of connective tissues, including bones and tendons.
- *Organic Extracts, i.e.*, protein substances formed in animals and some plants as a result of their metabolism. The flavor of meats and some plant foods is due to extractives.

Classification of proteins.—Proteins are classified in three main groups: (1) simple proteins which consist only of amino-acids, and when treated with enzymes or acids yield only amino-acids or their derivatives; (2) conjugated proteins, which consist of simple proteins with some other non-protein group, and yield amino-acids and some other body. This latter substance is nuclein in the nucleoproteins, a carbohydrate in the glycoproteins, a phospho body in the phosphoproteins, pigment in the chromoproteins, or

[7] Acids owe their characteristic properties to one or more hydrogen atoms that they hold in loose combination and part with in chemical reactions. It is called replaceable because it is replaced by the elements or radicals which unite with the remainder of the molecule in action.

hemoglobins, and a fatty substance in lecithoproteins. (3) The derived proteins include all the various proteins produced by the action of enzymes or reagents. Each splitting of a protein molecule gives substances with simpler composition, and to each such substance is given a special name, *i.e.*,—primary and secondary proteins→ metaproteins→ proteoses→ peptones→ peptids→ amino-acids.

Vitamins.—Many nutrition experiments have made it evident that for growth and maintenance the human animal requires not only certain amounts of proteins, carbohydrates, and fats, but certain other essential substances called vitamins. It has been demonstrated that the metabolism of proteins, carbohydrates, and fats is influenced by the presence or absence of vitamins. Their chemical composition is unknown, and they are designated differently by different writers, but the designations in most frequent use are, vitamin A, vitamin B, vitamin C, vitamin D, etc. Our knowledge of vitamins is confined chiefly to the effects caused by their lack in the diet of laboratory animals, principally rats, dogs and pigeons.

Vitamin A.—The effects of a diet deficient in this vitamin are (1) failure to grow, (2) failure of the normal secretion of the glands of the eyelid and (3) failure of the secretion of the sebaceous glands of the skin. The younger the animal, the greater the need for a generous supply of this vitamin if growth is to be maintained. Dry eyes or xerophthalmia favors bacterial infection with the result that animals deprived of this vitamin have sore, pus-filled eyes and a conjunctivitis that may result in blindness unless the vitamin is supplied in time. A similar disease has been described in children under conditions in which the diet lacked vitamin A, and the addition of this element to the diet was followed by quick relief. The lack of the sebaceous secretion is shown in the shaggy, unkempt appearance of the animal's coat.

Vitamin A is found mainly in animal fats (excepting lard) and in the foliage of plants. All liver fats are rich sources of supply, but cod liver oil is richest. Butter and the fat of egg-yolk contains much of it. Spinach, clover and alfalfa contain an abundance of it. Probably all leaves and grass contain some. Vitamin A tends to accompany the yellow pigment carotin. Carrots, sweet potatoes and yellow corn, all contain carotin and vitamin A but white potatoes and white corn lack both. Children obtain their supply from whole milk, butter or cream, and adults from

these sources or leafy vegetables. Nursing mothers require a generous supply of vitamin A, because the mammary gland secretes this requirement into the milk, even at the expense of the mother.

Some observers have been convinced that deficiency of this vitamin is mainly responsible for rickets, hence its former designation as *antirachitic*, but the factors concerned in the production of rickets are complex, and there is much experimental evidence indicating that the efficiency of cod-liver oil in curing rickets is due not to vitamin A, but to vitamin D, a different substance. Vitamin A is fairly resistant to high temperatures, and is not destroyed by boiling, unless the boiling is prolonged and the solution alkaline.

Vitamin B.—A diet deficient in this vitamin produces beri-beri in man, and a comparable condition of polyneuritis in the lower animals, hence it is designated as *antineuritic vitamin.* It is essential to growth, in fact, failure to grow due to a lack of it is even more marked than in the absence of vitamin A. The distinctive symptom of beri-beri or polyneuritis is a general inflammation of the nerves resulting in paralysis of the limbs, and unless death intervenes, a total paralysis. Early symptoms are loss of appetite, diarrhea, failure of digestion, anemia, emaciation, and an edematous condition of the skin.

Vitamin B is present in all animal tissues, but is not abundant; milk, eggs and brains probably contain more than other foods of animal origin. In plants the supply is abundant, being found in the green parts of spinach, clover and alfalfa, and in the root parts of beets, potatoes, onions, carrots, etc. Nuts and fruits are abundant sources. The richest stores are in the embryo of grains, especially wheat, and yeast. Vitamin B is not destroyed by drying or by cooking at ordinary temperatures if not too prolonged.

Vitamin C.—The effects of a lack of this vitamin are failure to grow, and the symptoms included under the term scurvy,[8] hence it is called antiscorbutic vitamin. Infantile and adult scurvy are now regarded as the same disease, the former being a milder

[8] The symptoms of scurvy are slight hemorrhages appearing as red spots under the skin, and forming hidden bleeding places in any of the muscles, internal organs, or periosteum of bone. Bleeding and soreness of the gums, decay of the teeth, and infections of the mouth are prominent symptoms. Extreme soreness of the joints, and changes in the ends of the bones, which become fragile and are easily broken, as well as a beaded condition of the ribs, are characteristic. Digestion is impaired. Constipation followed by diarrhea is usual. The heart hypertrophies and shows degenerative changes which often cause sudden death.

form. It may be due to an inadequate supply of vitamin C, as well as a total lack of it. This vitamin occurs in fresh fruits and vegetables, particularly in the juices of oranges, lemons and tomatoes. In fact all fruits, leafy parts of plants and all root-vegetables contain more or less. The antiscorbutic element in meat is low, and the quantity in milk depends on the food of the animal producing the supply. The diet of nursing mothers should contain a generous supply of this vitamin. It is the least resistant of the three vitamins, as heating and drying usually destroy it. This destruction does not occur in the absence of oxygen, or the presence of acids. Pasteurization of milk destroys vitamin C, hence the giving of orange juice or other antiscorbutics to children living on it. Canned tomato juice is equally effective and less expensive.

Vitamin D.—The experiments of Dr. McCollum[9] and his coworkers indicate that the wonderful efficiency of cod-liver oil in the prevention and cure of rickets is due to a specific vitamin other than vitamin A, to which they have given the name vitamin D. This vitamin is found in largest amounts in cod-liver oil, and in smaller amounts in butter fat. It is not present in vegetable oils, with the exception of a small amount in cocoanut oil.

Some investigators describe another vitamin which functions in relation to the normal course of pregnancy.

The way in which vitamins function is entirely unknown. It has been suggested that (1) they may act as catalysts, or hormones, (2) they may enter into the vital structure of the cells, and (3) they may act upon some of the glands of internal secretion. Such a small quantity of vitamins is required to produce satisfactory nutritive conditions that they cannot serve as fuel or meet energy requirements as proteins, carbohydrates and fats do.

Accessory articles of diet.—In addition to the foodstuffs proper, our foods contain numerous other substances which add to the attractiveness of food and stimulate appetite, but are not absolutely necessary for nutrition. These substances, differing in nature and importance, may be classified under the heads of:—

Flavors—Condiments: The various oils or esters that give odor and taste to foods. Salt, pepper, mustard, etc.

Stimulants: Tea, coffee, chocolate, cocoa, meat extracts, etc.

All the food principles, proteins, vitamins, fats, carbohydrates, water and salts, are contained in milk, vegetables, fruit, cereals, some fish, and liver; but meat other than liver, and eggs, lack

[9] McCollum, E. V., The Newer Knowledge of Nutrition.

carbohydrates. The carbohydrate in most fruit consists of sugar and cellulose, and that in cereals and most vegetables except beets, of cellulose and starch; in beets the starch is replaced by sugar.

DIGESTIVE PROCESSES

In a broad sense all the processes by which foods are rendered available to an organism are digestive processes. In this sense, many industrial and domestic processes are in line with digestion and often initiate the task which the digestive organs complete. This is particularly true of cooking, for by it various chemical changes are brought to pass; such, for example, as changing starches into dextrins, partially splitting fats into glycerin and fatty acids, and changing some proteins to the first stages of their decomposition products. A second reason for classifying cooking as a digestive process is that the appearance, odor, and taste of food are improved, and these facts stimulate the end-organs of the special senses, causing a reflex stimulation of the digestive mechanisms. In a third way cooking may profoundly aid digestion by killing parasites or bacteria which otherwise would gain a foothold in the alimentary canal and thus modify or change digestive processes. It is usual to describe digestion within the body as consisting of two processes, *i.e.*, mechanical and chemical.

Both the mechanical and chemical processes of digestion are controlled by the nervous system. Any severe strain or strong emotion which affects the nervous system unpleasantly, inhibits the secretion of the digestive fluids and interferes with digestion, often checking the appetite and even preventing the taking of food. On the other hand, pleasurable sensations aid digestion, hence the value of attractively served food, pleasant surroundings, and cheerful conversation.

Mechanical digestion.—Mechanical digestion is effected by various physical processes that occur in the alimentary canal. It is to be considered as preliminary to the more important chemical digestion. It serves four important purposes: (1) in taking food in and moving it along through the alimentary canal just rapidly enough to allow the required chemical changes to take place in each part; (2) in lubricating the food by adding the mucin and water secreted by the glands of the alimentary canal; (3) in liquefying the food by mixing it with the various digestive fluids; and (4) in separating the food into small particles, thereby increasing

the amount of surface to come in contact with the digestive fluids.

The mechanical processes consist of:—

1. Mastication.
2. Deglutition or swallowing.
3. Peristaltic action of the esophagus.
4. Movements of the stomach.
5. Movements of the intestines.
6. Defecation.

Chemical digestion.—The most essential part of digestion is chemical and is a process of hydrolysis which is dependent upon the presence of enzymes. The term hydrolysis means the breaking down of complex molecules into simpler ones with the absorption of water. An example of hydrolysis is the conversion of any of the complex sugars into simpler sugars.

$$\underset{\text{Complex Sugar}}{C_{12}H_{22}O_{11}} + \underset{\text{Water}}{H_2O} = \underbrace{\underset{\text{Glucose}}{C_6H_{12}O_6}.\underset{\text{Fructose}}{C_6H_{12}O_6}}_{\text{Invert Sugar}}$$

Thus the digestion of disaccharids involves only one splitting, while that of starch and proteins involves many splittings, but the process is always hydrolysis.

Necessity for chemical digestion.—Chemical digestion is necessary because foods, with the exception of simple sugars, cannot diffuse through animal membranes, and even if diffusion were possible, the tissues could not use them, hence they must be reduced to smaller molecules and to such standard substances as the tissues can use, *i.e.*, (1) simple sugars, resulting from the digestion of all carbohydrate foods; (2) glycerin and fatty acids, resulting from the digestion of fats; and (3) amino-acids, resulting from the digestion of proteins.

Cause of chemical digestion.—It is possible to make carbohydrates, fats, and proteins undergo the same changes outside the body as occur during digestion. Carbohydrates, fats, and proteins, if boiled with a mineral acid or subjected to the action of enzymes, will hydrolyze and split up into simpler substances. Within the body these changes take place at body temperature, and are due to the enzymes present in all of the digestive fluids.

Enzymes.—As stated on page 282 enzymes are organic substances which vary (hasten or retard) the speed of reactions, but do not initiate them. A distinction is frequently made between endoenzymes and exoenzymes. By endoenzymes is meant a group of intracellular enzymes which are held within the cells in some form of combination. Exoenzymes include the group of

enzymes which are eliminated from the cells in which they are formed, and are found in the secretions, for example, the ptyalin of the saliva, or the pepsin of the gastric fluid.

Classification of enzymes.—There is no consensus of opinion among physiologists or chemists as to the system to be followed in naming or classifying enzymes. Recently it has been suggested that an enzyme be designated by the name of the substance on which it acts, and that all of them be given the termination *ase.* According to this system the enzyme acting on starch would be amylase; that on maltose, maltase; that on fat, lipase. This suggestion has been followed in part only, as the older enzymes are still most frequently referred to under their original names. The following classification is a modification from a standard physiology.[10]

1. The sugar-splitting enzymes. These fall into two subgroups: (a) The inverting enzymes, which convert the double sugars or disaccharids into the monosaccharids. Examples: Maltase, which splits maltose to dextrose; invertase, which splits cane-sugar to dextrose and levulose; and lactase, which splits milk-sugar (lactose) to dextrose and galactose. (b) The enzymes, which split the monosaccharids. There is evidence of the presence in the tissues of an enzyme or enzymes capable of splitting the sugar of the blood and tissues (glucose) into lactic acid.

2. The amylolytic or starch-splitting enzymes. Examples: Ptyalin or salivary diastase, amylase, or pancreatic diastase. They cause hydrolysis of the starch molecule.

3. The lipolytic, or fat-splitting enzymes. Example: The lipase found in the pancreatic secretion, in the liver, connective tissues, blood, etc. They cause hydrolysis of the fat molecule.

4. The proteolytic or protein-splitting enzymes. Examples: Pepsin of gastric fluid, trypsin of pancreatic fluid. They cause hydrolysis of the protein molecule.

5. The clotting enzymes, which convert soluble to insoluble proteins. Example: The clotting of the casein of milk by rennin.

6. The oxidizing enzymes, or oxidases. A group of enzymes which set up oxidation processes.

7. The deaminizing enzymes. All amino-acids contain an NH_2 group which is split off by hydrolysis and is converted to ammonia— $\rightarrow NH_3$, and then probably to urea— $\rightarrow NH_2—CO—NH_2$.[11]

CHANGES THE FOOD UNDERGOES IN THE MOUTH

Mastication.—When solid food is taken into the mouth it is cut and ground by the teeth, being pushed between them again and again by the muscular contractions of the cheeks, and the movements of the tongue, until the whole is thoroughly crushed and ground down, thus exposing a larger surface to the action of the digestive fluids.

[10] Howell, W. H., "Text-book of Physiology," page 750, ninth edition.

[11] See page 405.

Insalivation.—During the process of mastication saliva is poured in large quantities into the mouth, and mixing with the food, lubricates, moistens, and reduces it to a soft, pulpy condition. A certain amount of air caught in the bubbles of the saliva also becomes entangled in the food, and this facilitates the penetration of the gastric fluid.

Secretion of saliva.—The secretion of saliva is the result of nerve impulses arising from several sources. (1) The thought or sight of food that is liked, especially when one is hungry—this is known as psychical secretion; (2) the flavoring substances and extractives stimulate the taste buds and olfactory nerve-endings; (3) the pressure of food in the mouth and the action of irritant substances; and (4) the movements of the jaws.

Saliva.—Saliva is a mixture of the secretions of all three pairs of salivary glands, as well as of the small glands of the mucous membrane of the mouth. It consists of water, inorganic salts, some mucin, an enzyme called *ptyalin*, and one called *maltase*. It has a specific gravity of 1.004 to 1.008 and is slightly alkaline (average pH is 7.2).

The functions of saliva.—Saliva has four distinct functions: (1) by softening and moistening the food it assists in mastication and deglutition; (2) by coating the food with mucin it lubricates it and insures a smooth passage along the esophagus; (3) by dissolving dry and solid food it provides a necessary step in the process of stimulating the taste nerves, and taste sensations play an important part in the secretion of gastric fluid; (4) by virtue of the enzymes which it contains it acts upon starch.

Ptyalin and maltase.—Ptyalin changes starch to dextrin and maltose, and maltase changes the latter to glucose This process is a complicated one consisting of a series of hydrolytic changes which take place in successive stages, and result in a number of intermediate compounds. The change is best effected at the temperature of the body,[12] in a slightly alkaline solution, saliva that is distinctly acid hindering or arresting the process. Boiled starch is changed more rapidly and completely than raw, but food is rarely retained in the mouth long enough for the saliva to more than begin the transformation of starch.

Deglutition or swallowing.—The softened and moistened food is brought together on the upper surface of the tongue and pressed backward through the fauces into the pharynx. Then the muscu-

[12] A temperature of 100° F. (37° C.) in the alimentary canal is necessary for digestion, hence iced drinks or iced foods that lower this temperature delay digestion.

lar bands in the wall of the pharynx contract and force the food into the esophagus. At this moment breathing has to be suspended and the passages closed against the possible entrance of food. The soft palate is drawn back, thus protecting the nasal passages, and the larynx is shielded by being pulled forward under the root of the tongue, and has an additional safeguard through the folding down upon it of the epiglottis. When food is once within the esophagus, breathing may be resumed and the downward passage of the food is assisted by the peristaltic action of the esophagus.

Peristalsis.—Peristalsis occurs in such tubular viscera as the esophagus, stomach, intestines, etc., which possess muscular coats. Peristalsis consists of a series of wave-like contractions of the circular fibers which affect successive portions of the tube from above downward. The constricted portion is always preceded by an area of relaxation, which renders the contraction more effective in forcing the contents onward. The direction is always the same, and the action is under the control of the nervous system.

Summary.—During the process of mastication, insalivation, and deglutition the food is first reduced to a soft, pulpy condition; second, any starch it may contain begins to be changed into sugar; third, it acquires a more or less alkaline reaction.

Vomiting.—Under ordinary circumstances the contractions of the cardiac sphincter muscle prevent the regurgitation of food, but strong contractions of the stomach or spasmodic contractions of the abdominal muscles may, if the diaphragm is fixed, force the contents of the stomach through the esophagus and mouth to the exterior. This is called vomiting.

CHANGES THE FOOD UNDERGOES IN THE STOMACH, OR STOMACH DIGESTION

The food which enters the stomach is delayed there by the contraction of the sphincter muscles at the cardiac and pyloric openings. The cavity of the stomach is always the size of its contents, which means that when there is no food in it, it is contracted, but when food enters, it expands just enough to hold it. Within a few minutes after the entrance of food small contractions start in the middle region of the stomach and run toward the pylorus. These contractions are regular and become more and more forcible as digestion progresses. As a result of these movements the food is macerated, mixed with the acid gastric fluid,

and reduced to a thin liquid mass called **chyme.** At certain intervals the pyloric sphincter relaxes and the wave of contraction forces some of the chyme into the duodenum. The fundal end of the stomach does not take part in these movements, but serves as a reservoir for food which is under slight pressure, as the muscles are in a state of continual contraction or tone. Due to the lack of movement and the muscular tone, the gastric fluid cannot penetrate the bolus of food, and the ptyalin and maltase with which it became mixed in the mouth continue their action, and the digestion of starch continues for about half an hour. As the chyme is gradually forced into the duodenum, the pressure of the fundus forces the food into the pyloric end.

The stomach is admirably adapted to receive a large amount of food within a short period of time. It reduces this food to chyme, and at intervals charges the intestine with small amounts of this chyme in such condition as to admit of rapid digestion. It seems probable that without the stomach, our mode of eating would have to be changed, as it would not be possible to load the intestine with the amount of food ordinarily consumed at a meal.

Time required for stomach digestion.—It is obvious that the time required for gastric digestion depends upon the nature of the food eaten. An average meal of mixed food requires about five hours for gastric digestion. The ejection of chyme through the pylorus occurs at regular intervals, and is supposed to depend upon the consistency and acidity of the chyme. Solid particles forced against the pylorus tend to keep it closed, but a finely divided condition of the chyme and acidity produce relaxation of the pyloric sphincter. In the intestines hydrochloric acid has a contrary effect, as it causes a contraction of the sphincter, which remains closed after each ejection until the acidity has been neutralized.

Secretion of gastric fluid.—The secretion of gastric fluid is constant. Even in the period of fasting there is a small continuous secretion, but during the act of eating and throughout the period of digestion, the rate of secretion is greatly increased. This rate is maintained by two factors: (1) *psychical* or nervous, the sensations of eating; the taste and odor of food stimulate the sensory nerves situated in the mouth and nose. These afferent impulses are transferred through nerve centers to efferent fibers of the vagus nerve, and thus are carried to the stomach. (2) *Chemical,* (*a*) by secretagogues contained in certain foods and (*b*) by secretagogues contained in the products of digestion. Certain

foods, such as meat juices and extracts, contain substances called secretagogues or hormones which are supposed to act directly upon the nerves of the pyloric mucous membrane and form a substance called *gastrin* or *gastric secretin*, which is absorbed into the blood and carried to the gastric glands. This substance stimulates the glands to secretion. Other foods, such as milk, bread, white of egg, etc., do not appear to contain secretagogues. When such foods are eaten, a psychical secretion is started and when this has acted, some products of their digestion in turn become capable of stimulating a further secretion of gastric fluid.

Gastric fluid.—Gastric fluid is secreted by the gastric glands[13] lining the mucous membrane of the stomach. It is a thin, colorless, or nearly colorless liquid with a strong acid reaction (pH is 1.77) and a specific gravity of about 1.002–1.003. The quantity secreted depends upon the amount of food to be digested. Upon analysis it is found to contain some protein, some mucin, and inorganic salts, but the essential constituents are hydrochloric acid and two or possibly three enzymes—pepsin, rennin, and lipase.

Hydrochloric acid.—It is generally believed that the parietal cells of the gastric glands secrete the hydrochloric acid, from chlorids found in the blood. The chief chlorid is sodium chlorid (NaCl), and by some means this is decomposed; the chlorin (Cl) combines with hydrogen (H), and is then secreted upon the free surface of the stomach as hydrochloric acid (HCl). In normal gastric fluid it is found in the proportion of 0.2 per cent. It serves (1) to activate pepsinogen and convert it to pepsin; (2) provides an acid medium which is necessary for the pepsin to carry on its work; (3) swells the protein fibers, thus giving easier access to pepsin; (4) it helps in the inversion of cane-sugar, which is the easiest of the disaccharids to invert; (5) it acts as a disinfectant and kills many bacteria that enter the stomach, and (6) it helps to regulate the opening and closing of the pyloric valve.

If the secretion of hydrochloric acid is excessive, it causes hyperacidity of the gastric fluid, which is one of the underlying causes of gastritis and gastric ulcer.

Pepsin.—Pepsin is supposed to be formed in the pyloric glands and the chief cells of the gastric glands. It is present in these cells in the form of a zymogen, an antecedent inactive substance called pepsinogen which is quickly changed to active pepsin by the action of hydrochloric acid.

[13] See page 340.

Pepsin is a weak proteolytic enzyme requiring an acid medium in which to work. It has the property of hydrolyzing proteins through several stages into proteoses and peptones. This action is preparatory to the more complete hydrolysis that takes place in the intestines under the influence of trypsin and erepsin, for peptones are not absorbed but suffer a further hydrolysis to amino-acids.

Rennin.—Rennin, like pepsin, is supposed to be formed in the chief cells of the gastric glands in a zymogen form, the *prorennin* which after secretion is converted to the active enzyme. So far as is known, this enzyme acts *only* upon the soluble protein of milk, which is called *caseinogen*. It converts this substance into a clotted mass called curd; the digestion of which is carried on by the pepsin, and later in the intestine by the trypsin.

Various observers have described other enzymes in addition to the pepsin and rennin, but the evidence regarding these is uncertain. It is probable that the ptyalin swallowed with the food continues the digestion of starchy material in the fundus for some time. Regarding the fats, it is believed that they undergo no true digestive change in the stomach. They are set free from their mixture with other foodstuffs by the dissolving action of the gastric fluid; they are liquefied by the heat of the body, and are scattered through the chyme in a coarse emulsion by the movements of the stomach, all of which favors the subsequent action of the pancreatic fluid. Emulsified fats like cream are acted upon to a limited extent by a third enzyme called *gastric lipase*, but the acid condition of the stomach contents prevents any considerable change of this sort.

Summary.—The stomach serves as (1) a place for temporary storage and maintains a gradual delivery to the intestine. (2) The movements are adapted to promote the mechanical reduction of food. (3) Salivary digestion of starch continues until the acidity is everywhere established. (4) Gastric digestion affects proteins chiefly and is incomplete. (5) There is some digestion of emulsified fat. (6) The germicidal action of the hydrochloric acid enables the stomach to serve as a disinfecting station.

Inhibition of gastric digestion.—The secretion of gastric fluid is inhibited by stimulation of the sympathetic system, so that anger, pain, worry, and also a distaste for food may delay digestion. Secretion is also inhibited by active exercise soon after a meal, because active exercise increases the amount of blood in the skeletal muscles, and decreases the supply to the stomach.

When gastric digestion is much delayed, bacteria and acids, especially lactic acid, are likely to cause fermentation of the starches and sugars, producing gas which may cause distress.

CHANGES THE FOOD UNDERGOES IN THE SMALL INTESTINE

The chyme, entering the duodenum, after an ordinary meal, is a mixture of various matters. It probably contains proteoses and peptones derived from the proteins; dextrins and sugars from the carbohydrates; traces of glycerin and fatty acids from the fats; portions of all the foods not yet digested; hydrochloric acid from the gastric fluid; and lactic acid produced by fermentation. It is in the intestines that this mixture undergoes the most profound digestive changes. These changes which constitute intestinal digestion are effected by: (1) the movements of the intestines, (2) the pancreatic fluid, (3) the succus entericus or secretion of the intestinal glands, and (4) the bile.

It is convenient to describe the secretion and digestive action of these three fluids separately, but it must be remembered that they act simultaneously.

Movements of the small intestine.—The movements of the small intestine are of two kinds: (1) peristaltic and (2) rhythmic segmentation.

(1) A peristaltic movement may be defined as a quick succession of waves of contraction and inhibition passing slowly along the intestine. The wave of contraction begins at a certain point, passes downward away from the stomach, and is always preceded by an area of inhibition or relaxation. The purpose of it is to pass the food slowly forward, and it is obvious that the wave of contraction is more effective in forcing the contents forward because just in front of it the intestine is relaxed.

(2) The movements of pendular or rhythmic segmentation consist of local constrictions of the intestinal wall which occur rhythmically at points where masses of food lie. The purpose of these constrictions is to divide the string of food into a number of equal segments. Within a few seconds each of these segments is halved and the corresponding halves of adjoining segments unite. Again constrictions recur and these newly formed segments are divided, and the halves reform in the same position as they had at first. In this way every particle of food is brought into intimate contact with the valvulæ conniventes and is thoroughly mixed with the digestive fluids.

Secretion of pancreatic fluids.—Just as the chewing and swallowing of food starts gastric secretion, so the acidity of the chyme starts pancreatic secretion. It is controlled by a hormone called *secretin*, which originates in the mucous membrane of the duodenum. Secretin is held in the cells in an inactive form called *prosecretin*. When the acid chyme is discharged into the intestine prosecretin is changed to secretin, which is absorbed by the blood and carried to the pancreas,[14] which it stimulates to activity.

Pancreatic fluid.—Healthy pancreatic fluid is a clear, somewhat viscid fluid, with a decided alkaline reaction (pH is 8.0). It contains few solids and is dependent for its remarkable power on three enzymes: (1) trypsin, (2) amylase, (pancreatic diastase) and (3) lipase (steapsin). Some authorities state that the secretion contains a fourth enzyme, *i.e.*, rennin.

Action of pancreatic fluid upon food.—Pancreatic fluid has the power of acting on all the foodstuffs, proteins, carbohydrates, and fats. This action is due to its enzymes.

(1) *Trypsin.*—Trypsin is secreted in the form of a zymogen called trypsinogen, and is activated by enterokinase, an enzyme which is contained in the mucous membrane of the small intestine. Trypsin, like pepsin, causes hydrolysis of proteins, but the action is more rapid and powerful, and the protein molecule is broken up into simpler substances than peptones, depending on the amount of trypsin and the time that it acts. If complete hydrolysis takes place, the end-products consist chiefly of amino-acids. Trypsin attacks proteins in slightly acid, neutral, or strongly alkaline mediums. The preliminary action of pepsin, or a protein molecule, hastens the action of trypsin, and renders it more complete than if the trypsin acted alone.

(2) *Amylase* (*Diastase or Amylopsin*).—The action of amylase is similar to that of ptyalin. It causes hydrolysis of starch with the production of achroödextrin and maltose. The starchy food that escapes digestion in the mouth and stomach becomes mixed with this enzyme and continues under its action until the colic valve is reached. Before absorption, achroödextrin and maltose are further acted upon by the maltase of the intestinal secretion and converted to dextrose.

(3) *Lipase* (*Steapsin*).—Lipase is an enzyme capable of hydrolyzing fats to glycerin and fatty acids. The process of

[14] Also stimulates liver and small intestine. See page 382.

hydrolysis is preceded by emulsification[15] which is dependent upon the formation of soaps. The lipase splits some of the fats to fatty acids and glycerin. The fatty acids combine with the alkaline salts to form soaps (saponification). The presence of a small amount of soap formed in this way at the beginning of the reaction is instrumental in causing the emulsification of the neutral fat. This emulsification increases the surface of fat exposed to the chemical action of the lipase and from a physiological standpoint is regarded as a preparatory process. Glycerin and fatty acids are absorbed by the epithelium of the intestine, and again combine to form fat, but it is probable they combine in such proportions as to make fat characteristic of the human animal. The action of lipase is said to be reversible, *i.e.*, it causes both the splitting of the fats and the synthesis of the split products, not only in the intestines, but in the various tissues, during the metabolism or the storage of fat. Lipase is found in blood and in many tissues,—muscle, liver, mammary glands, etc.

Succus entericus, or intestinal fluid.—Succus entericus is the secretion of the intestinal glands. It is a clear, yellowish fluid, having a marked alkaline reaction and containing a certain quantity of mucin. Its secretion is thought to be promoted by secretin. There is much disagreement as to the properties and importance of this secretion. It is said to have little or no digestive action except upon starches; nevertheless, the general tendency is to attribute to it, plus the intracellular enzymes, a larger share in the work of digestion than was formerly granted. These intracellular or endoenzymes are not secreted into the lumen of the intestine but are held within the cells, and, strictly speaking, are not a constituent of the intestinal fluid. However, it is their action on food that is the important contribution of the intestinal glands to digestion. These enzymes and their actions are as follows:—

Enterokinase.—This enzyme activates the trypsinogen of pancreatic fluid and converts it into trypsin.

Erepsin.—This enzyme hydrolyzes proteoses and peptones to amino-acids, thus completing the work begun by the pepsin and trypsin. It is claimed that it occurs not only in the intestinal mucosa but also in the liver, kidney, pancreas, and possibly in other tissues.

[15] An oil is emulsified when it is broken up into minute globules that do not coalesce. Artificial emulsions may be made by vigorous and prolonged shaking of oil in a viscous solution of soap, mucilage, etc.

Inverting enzymes.—These enzymes are three in number and convert disaccharids into monosaccharids. 1. Maltase acts upon the products formed in the digestion of starches, *i.e.*, maltose and dextrin, and converts them to dextrose. 2. Invertase or sucrase acts upon sucrose and changes it to dextrose and levulose. 3. Lactase acts upon lactose and changes it to dextrose and galactose. This inverting action is necessary because double sugars cannot be used by the tissues and would escape in the urine, but in the form of simple sugars they are readily used by the tissues.

Nuclease.—An enzyme to which this name may be given is said to occur in the small intestine. It acts upon the nucleic-acid component of nucleoproteins.

Secretin.—This is not an enzyme, but a hormone, and plays an important part in the control of the secretion of the pancreas, liver and small intestine. It is secreted or formed in the intestinal mucosa in a preliminary form called prosecretin, and under the influence of acid is changed to secretin. Secretin is absorbed and carried by the blood to the organs which it stimulates to activity.

Bile.—Bile is an alkaline liquid of a specific gravity of 1.010 to 1.040 and may be golden yellow, green, or brown in color.[16] The pigments to which the color is due are derived chiefly from the hemoglobin of the disintegrated erythrocytes, or may depend upon the nature of the food eaten.

The quantity secreted in twenty-four hours varies with the amount of food taken, but is estimated at about one to one and two-thirds pints (500 to 800 cc.). It consists of water, inorganic salts, bile-salts, *i.e.*, sodium taurocholate and sodium glycocholate; lecithin, cholesterin, and bile pigments. The bile-salts are important constituents as they are not readily lost from the system, but are to a considerable extent alternately excreted into the duodenum and then absorbed from the small intestine and secreted again and so on. It is believed they stimulate the activity of the liver and may have several other functions. The mucous membrane of the bile-ducts and gall-bladder secrete a mucilaginous protein called nucleo-albumin which is added to the bile.

Secretion of Bile.—The secretion of bile is continuous but the amount varies with the quantity and composition of the portal blood. It is also thought that the presence of bile in the intestines stimulates secretion in the liver, and is due to the bile-salts which

[16] The color of bile is determined by the respective amounts of the bile pigments: (1) biliverdin, and (2) bilirubin, that are present.

act as cholagogues. In addition there is evidence that the action of the secretin is not limited to stimulating pancreatic secretion, but also stimulates bile secretion. Bile enters the duodenum only during the period of digestion. During the intervening period it is prevented from entering the duodenum by the sphincter which closes the common bile-duct, and consequently backs up into the gall-bladder. Apparently the ejection of chyme into the duodenum excites a contraction of the gall-bladder and an inhibition of the sphincter which results in an ejection of bile.

Bile probably contains coenzymes and activates the lipase of the pancreatic fluid. Its physiological effects may be grouped as follows:—

1. *Digestive secretion.*—It serves as a digestive secretion by accelerating the action of the lipase of the pancreatic fluid in splitting fats to glycerin and fatty acids, and aids in the absorption of these products. If fat is not absorbed, it coats the other foods in the intestines and thus tends to prevent their digestion and absorption.

2. *Excretion.*—Its value as an excretion we know little about, but it is thought to serve as a channel by which bile pigments are excreted.

3. *Antiseptic.*—It has a feeble and questioned antiseptic action upon the intestinal contents, and its presence limits putrefaction to some extent.

Jaundice.—When the flow of bile through the bile-duct is interfered with, bile gets into the blood, and is carried to all parts of the body, producing a condition of jaundice, which is characterized by a yellow discoloration of the skin and of the whites of the eyes. The urine is of a greenish hue because of the extra quantity of pigment eliminated by the kidneys, and the stools are grayish in hue, due to the lack of bile. Gall-stones in the gall-bladder or ducts, plugging of the ducts with mucus, and constipation, may interfere with the excretion of bile.

Gall-stones.—Cholesterin may become so concentrated in the gall-bladder that it tends to crystallize out, and these crystals form gall-stones. Very trifling changes such as catarrhal conditions, may cause this crystallization. Catarrhal conditions are often due to the typhoid bacilli and colon bacilli. The latter, as their name implies, are always present in the colon. Gall-stones may be found in the cystic and hepatic ducts as well as in the gall-bladder, but it is believed they are usually formed in the latter.

Action of bacteria in small intestine.—Numerous bacteria which are able to hydrolyze carbohydrates and proteins are constantly present in the small intestine. Fermentation of the carbohydrates gives rise to organic acids, such as lactic and acetic, but none of the products of this fermentation are considered toxic. On the other hand, the putrefaction of proteins gives rise to a number of end-products that are distinctly toxic. Under normal conditions and on a mixed diet, carbohydrate fermentation is the characteristic action of the bacteria in the small intestine; while protein putrefaction occurs in the large intestine. The reason for this seems to be that carbohydrates serve to protect proteins because some of the bacteria of the small intestine, *i.e.*, bacillus coli, will not attack proteins as long as carbohydrate material is present. In addition, the organic acids produced by the fermentation of carbohydrates tend to neutralize the alkalinity of the intestinal secretion, and may even give an acid reaction. An acid reaction is unfavorable to the action of the bacteria that hydrolyze proteins, and in this way putrefaction in the small intestine is prevented. From this it follows that the nature of bacterial activity in the small intestine depends upon the character of the diet, which may be intentionally chosen to favor one or the other kind.

Time required for digestion in small intestine.—This is difficult to state because many factors enter in. It depends largely on the varying proportions of the different foods included in a meal. According to observations made upon a patient with a fistula at the end of the small intestine, food begins to pass into the large intestine in from two to five and one-quarter hours after eating, and it requires nine or more hours before the last of a meal has passed the colic valve; this estimate of course includes the time in the stomach.[17]

CHANGES THE FOOD UNDERGOES IN THE LARGE INTESTINE

Movements of the large intestine.—After the food passes from the small intestine into the large intestine, its regurgitation is prevented by the closure of the colic valve. When the cecum becomes filled, strong contractions of the walls exert pressure upon the contained food and force it into the ascending colon. X-ray examinations in man show strong peristaltic movements

[17] Sherman quotes a case in which the time from the eating of food until the last portion has passed into the large intestine was 9 to 23 hours. "Chemistry of Food and Nutrition."

designated as *mass peristalsis* in the large intestine. These occur only three or four times a day and last only a short time, but they move the mass from one division to another, *i.e.*, from the ascending to the transverse colon. Some investigators connect them with eating and assume that the entrance of food into the stomach sets up a reflex movement in the colon. In between these movements there are constant rhythmic contractions.

Secretion of the large intestine.—The secretion of the large intestine contains much mucin, shows an alkaline reaction, and is not characterized by the presence of enzymes. When the contents of the small intestine pass the ileocecal valve, they still contain a certain amount of unabsorbed food material. This remains a long time in the intestine, and since it contains the digestive enzymes received in the duodenum, the process of digestion and absorption continues.

Action of bacteria in large intestine.—Protein putrefaction due to the action of bacteria is a constant and normal occurrence in the large intestine. The reaction is alkaline, and whatever protein may have escaped digestion and absorption is acted upon by the bacteria and undergoes putrefactive fermentation. The splitting of the protein molecule by this process is very complete, and the end-products differ from those resulting from the hydrolysis caused by acids or enzymes. The list of end-products of putrefaction is a long one and includes not only peptones, proteoses, ammonia and amino-acids, but also indol, skatol, phenol, fatty acids, carbon dioxide, hydrogen sulphide, etc. Some of the latter are given off in the feces, others are absorbed and carried to the liver where they are changed to less toxic compounds such as indican and ultimately excreted in the urine. Therefore the amount of indican in the urine is indicative of the degree of intestinal putrefaction that is going on. Even though indican and allied compounds are less toxic than those from which they are derived, they are more or less poisonous, and the feelings of malaise associated with constipation are thought to be due to the presence of these substances in the blood. Some investigators believe that the constant presence of the products of putrefaction in the blood is injurious to the tissues and tends to promote arteriosclerosis. A conservative view is that bacteria confer no positive benefit, but under normal conditions the body is able to neutralize their injurious action.

The feces.—The character and quantity of food, determine the amount and composition of feces. Upon a diet of vegetables, especially those containing a large amount of cellulose, the feces are bulky; they are less so on an ordinary mixed diet, and on a diet of meats alone, they are small in amount and dark in color. The only value of cellulose in the diet is to add bulk to the intestinal contents. The feces consist of: (1) the undigested and indigestible parts of the food, (2) the products of bacterial decomposition, *i.e.*, indol, skatol, etc., (3) great quantities of bacteria of different kinds, (4) bile and other secretions, (5) some of the purin bases, (6) inorganic salts and (7) mucin and epithelial cells from the walls of the intestine.

Defecation.—The anal canal is guarded by an internal sphincter muscle and an external sphincter which are normally in a state of tonic contraction and protect the anal opening. Normally the rectum is empty until just before defecation. Various stimuli (depending on one's habits) will produce peristaltic action of the colon, so that a small quantity of feces enters the rectum. This irritates the sensory nerve-endings and causes a desire to defecate. The voluntary contraction of the abdominal muscles, the descent of the diaphragm, and powerful peristalsis of the colon all combine to empty the colon and rectum.

One of the commonest causes of constipation is the retention of feces in the rectum because of failure to act on the desire for defecation. After feces once enter the rectum there is no retro-peristalsis to carry them back to the colon, and the sense of irritation becomes blunted. The desire may not recur for twenty-four hours, and during this time the feces continue to lose water, become harder, and more difficult to expel. The best means to prevent and overcome constipation are: (1) act upon the desire for defecation, and have a regular time for doing so; (2) use a liberal amount of fruit and vegetables. Some authorities teach that a certain amount of indigestible material in the diet is wholesome. It stimulates the lining of the intestines, promotes peristalsis, and as it is pushed along the tube takes with it the less bulky but more toxic wastes. (3) Form the habit of daily exercise of the abdominal muscles.

SUMMARY

Man's Dependence on Plants

- Life processes in plants are constructive
  - Cells of green plants contain chloroplasts—synthesize CO_2 and H_2O into carbohydrates.
  - Plant cells using carbohydrates as a basis make fats and with nitrates make proteins.
- Life processes in man are first destructive, then constructive
  - Process of digestion splits carbohydrates, fats and proteins of food into simple sugars, glycerin and fatty acids, and amino-acids; the tissue cells can synthesize these standard substances into carbohydrates, fats and proteins characteristic of their own tissues.

Food

Any substance taken into the body to
1. Provide material for growth of tissues.
2. To yield energy.
3. To regulate body processes.

Classification

Chemical analysis shows that elements found in body are found in food.

Nutrients or Food Principles:
- Water.
- Mineral matter or inorganic salts.
- Carbohydrates.
- Fats.
- Proteins.
- Vitamins.

Water

H_2O is a compound of hydrogen and oxygen.

Enters into composition of all tissues, even bone contains 50 per cent.

Supplies fluid for:
- Secretions.
- Chemical reductions.
- Transfer of food material.
- Elimination of waste.

Important in heat regulation.

Constitutes 66 per cent of body weight, and five-sixths of daily income.

Under normal conditions amount in body remains about the same.

Salts

- Iron.
- Calcium.
- Sodium.
- Potassium.
- Magnesium.
- Phosphorus.
- Sulphur.
- Chlorin.
- Iodin.
- Fluorin.
- Silicon.

Functions
1. Essential part of all tissues.
2. Regulate osmotic interchanges.

Salts

Functions

3. Reduce permeability of the walls of the blood-vessels.
4. Iron is a constituent of hemoglobin.
5. Help to maintain the acid-base equilibrium of the liquids and tissues of the body.
6. Essential for tone of visceral muscle.
7. Calcium assists in the clotting of blood.
8. Regulate the irritability of nerves.
9. Sodium chlorid furnishes chlorin for hydrochloric acid.
10. Enter into composition of bones and give them rigidity.

Phosphates, calcium, iron, and sulphur enter into organic combinations.

Fluorin and silicon occur in bones and teeth.

Carbohydrates

Consist of C, H, and O, the two latter in the proportion to form water. Include sugars and starches.

Monosaccharids

Contain one sugar group.

Glucose or dextrose $C_6H_{12}O_6$ } Invert sugar.

Fructose or levulose $C_6H_{12}O_6$ }

Disaccharids

Contain two sugar groups.

Sucrose or cane-sugar $C_{12}H_{22}O_{11}$.

Lactose or milk-sugar $C_{12}H_{22}O_{11}$.

Maltose or malt-sugar $C_{12}H_{22}O_{11}$.

Polysaccharids

Contains many sugar groups.

Starch $(C_6H_{10}O_5)n$.

Cellulose $(C_6H_{10}O_5)n$.

Glycogen $(C_6H_{10}O_5)n$.

Dextrin $(C_6H_{10}O_5)n$.

Fats

Used in anatomic sense = adipose tissue.

Used in chemical sense = compound of C, H, and O, but the H content is relatively high.

Fats are liquid at body temperature.

Made from one molecule of glycerin and three molecules of fatty acid. Reaction comparable to neutralization of an acid by a base.

Stearic acid + Glycerin → Stearin + Water

$3\ H.C_{18}H_{35}O_2 + C_3H_5(OH)_3 \rightarrow C_3H_5(C_{18}H_{35}O_2)_3 + 3\ H_2O$

Under influence of body enzymes split into substances out of which they are built. Reaction reverse of above.

Stearin + Water → Glycerin + Stearic acid

$C_3H_5(C_{18}H_{35}O_2)_3 + 3\ H_2O \rightarrow C_3H_5(OH)_3 + 3\ H.C_{18}H_{35}O_2$

Proteins

Consist of C, H, N, O; S, P, and other elements may be present.

Differ from carbohydrates and fats in having nitrogen, hence called nitrogenous.

Built up of simpler substances called amino-acids.

Amino-acids contain an amino radical (NH_2) instead of a replaceable hydrogen.

Acetic acid—CH_3 COOH—for replaceable H substitute $(NH_2) \rightarrow CH_2\ (NH_2)$ COOH. = Amino-acetic acid.

Propionic acid—C_2H_5 COOH—for replaceable H substitute $(NH_2) \rightarrow C_2H_4\ (NH_2)$ COOH. = Amino-propionic acid.

About twenty amino-acids have been described, and various combinations result in many different kinds of proteins, *i.e.*, milk, meats, fish, egg, peas, beans, lentils, and peanuts.

Proteins

- **Examples of protein constituents of food**
  - Albumin—found in egg, milk, meat.
  - Caseinogen—found in milk.
  - Gluten—gummy substance in wheat.
  - Legumin—found in legumes.
  - Gelatin—drived from connective tissues including bone and tendon.
  - Organic extracts—flavor of meats and some plant foods due to these.
- **Classification**
  - Simple
    - Consists only of amino-acids.
    - Yield only amino-acids or derivatives.
  - Conjugated
    - Consist of simple proteins with some other nonprotein group — yield amino-acids and some other body.
    - Nucleoproteins — yield amino-acids and nuclein.
    - Glycoproteins—yield amino-acids and a carbohydrate.
    - Phosphoproteins—yield amino-acids and a phospho body.
    - Hemoglobins—yield amino-acids and hematin.
    - Lecithoproteins — yield amino-acids and a fatty substance.
  - Derived
    - Various proteins produced by the action of enzymes, *i.e.*, primary and secondary proteins, metaproteins, proteoses, peptones, peptids, amino-acids.

Vitamins

- Chemical composition unknown.
- Essential for growth, nutrition and metabolism of fats, proteins and carbohydrates.
- **Vitamin A**
  1. Lack of this vitamin results in (1) failure to grow; (2) failure of secretion of glands of eyelids; (3) failure of sebaceous secretion of skin.
  2. Occurs in animal fats (except lard), liver fats, especially cod-liver oil, and foliage of plants. Tends to accompany yellow pigment, carotin.
  3. Not destroyed by boiling unless long-continued or solution is alkaline.
- **Vitamin B Antineuritic**
  1. Lack of this vitamin results (1) in failure to grow; (2) symptoms of beri-beri or polyneuritis.
  2. Occurs in small amounts in animal tissues, abundant in plants.
  3. Not destroyed by drying or cooking at ordinary temperatures.
- **Vitamin C Antiscorbutic**
  1. Lack of this vitamin results in failure to grow and (2) symptoms of scurvy.
  2. Occurs in fruits, oranges, lemons. tomatoes, leafy parts of plants and root vegetables.
  3. Least resistant to drying and heating unless done in presence of acids, or absence of oxygen.
- **Vitamin D Antirachitic**
  - Found in cod-liver oil.
  - Specific for rickets.
- Action may be as (1) catalysts or hormones, (2) may enter into structure of cells, and (3) may act upon endocrin glands.

- **Accessory Articles of Diet**
  - Flavors and condiments: The various oils and esters that give odor and taste to food. Salt, pepper, mustard, etc.
  - Stimulants: Tea, coffee, chocolate, cocoa, meat extracts.
- **Digestive Processes**
  - **Mechanical**
    - Mastication.
    - Deglutition or swallowing.
    - Peristaltic action of esophagus.
    - Movements of stomach.
    - Movements of intestines.
    - Defecation.
  - **Chemical**
    - Splitting of complex substances into simpler ones. Process of hydrolysis that is dependent on enzymes.
    - Rendered necessary by variety and complexity of foods, which must be reduced to standard and simple substances that the tissues can use, *i.e.*,
      - Simple sugars.
      - Glycerin and fatty acids.
      - Amino-acids.
- **Enzymes**
  - Substances produced by living cells which act by catalysis, *i.e.*, vary, hasten, or retard speed of reactions.
  - **Classification according to where found**
    - Endoenzymes—held within cells in which they are formed.
    - Exoenzymes—eliminated from cells in which formed.
  - **Classification according to action**
    1. Sugar-splitting
       - *a*. Inverting.
       - *b*. Enzymes which act on simple sugars.
    2. Amylolytic or starch-splitting.
    3. Lipolytic or fat-splitting.
    4. Proteolytic or protein-splitting.
    5. Clotting enzymes.
    6. Oxidizing enzymes, or oxidases.
    7. Deaminizing enzymes.

LIST OF DIGESTIVE FLUIDS AND CHIEF ENZYMES

Digestive Fluids	Enzymes	Functions
Saliva	Ptyalin or salivary diastase	Hydrolyzes starch to dextrin and sugar (maltose).
	Maltase	Aids the change of maltose to glucose.
Gastric Fluid	Pepsin plus hydrochloric acid	Hydrolyzes proteins into proteoses and peptones.
	Rennin	Curdles the caseinogen of milk.
	Gastric lipase	May initiate the digestion of emulsified fats such as cream.
Pancreatic Fluid	Trypsin	In a slightly acid, neutral, or strongly alkaline medium, splits proteoses into peptones and amino-acids.
	Amylase or Diastase	Hydrolyzes starch to dextrin and sugar (maltose).
	Lipase (Steapsin)	Splits fats to glycerin and fatty acids. This action is reversible.
		Activates union of fatty acids with alkalies—saponification.

DIGESTIVE FLUIDS	ENZYMES		FUNCTIONS
Succus Entericus	Enterokinase		Activates the trypsinogen, and converts it into trypsin.
	Erepsin		Hydrolyzes proteoses and peptones to amino-acids.
	Inverting	Maltase	Hydrolyzes dextrin and maltose to dextrose.
		Invertase	Hydrolyzes sucrose to dextrose and levulose.
		Lactase	Hydrolyzes lactose to dextrose and galactose.
Bile	No enzyme		Serves as coenzyme and activates the lipase of the pancreatic fluid.

Changes Food undergoes in Mouth

- Mastication (chewing).
- Insalivation (mixing with saliva).
- **Saliva**
  - Secreted by salivary glands: Parotid, Submaxillary, Sublingual } and mucous glands of mouth.
  - Stimulated by:
    - Thought or sight of food.
    - Flavoring substances and extractives.
    - Pressure of food and action of irritant substances.
    - Movements of the jaws.
  - Consists of water, mucin, and enzymes—**ptyalin** and **maltase.**
  - Specific gravity 1.004-1.008. Slightly alkaline reaction.
  - **Functions**
    1. Assists in mastication and deglutition.
    2. Serves as a lubricant.
    3. Dissolves or liquifies the food, thus stimulating the taste nerves, and indirectly the secretion of gastric fluid.
    4. Ptyalin hydrolyzes starch to dextrin and maltose; maltase changes maltose to glucose.
- **Deglutition** (swallowing).

Peristasis—consists of series of wave-like contractions of the circular fibers of such tubular viscera as the esophagus, stomach, and intestines.

Stomach Digestion

- Definition—changes the food undergoes in the stomach.
- Time required—depends on nature of food eaten, average meal of mixed food requires about five hours.
- Food held in stomach by contraction of cardiac and pyloric sphincters.
- Cavity size of contents—never empty—always few cc. of gastric fluid in stomach.
- When food enters—expands just enough to receive it—contractions start—food macerated, mixed with gastric fluid and reduced to **chyme.**
- Salivary digestion continues until gastric fluid penetrates bolus of food.

Stomach Digestion

- **Dependent on Gastric Fluid**
  - Periods of fasting—secreted in small amount.
  - While eating and during period of digestion—amount increased.
  - Stimulation
    - Psychical or Nervous
      - Sensations of eating.
      - Taste and odor of food.
    - Chemical
      - Secretagogues contained (1) in food and (2) in products of digestion.
      - Secretin.
  - Secreted by glands of stomach
    - Cardiac.
    - True gastric or peptic.
    - Pyloric.
  - Acid reaction due to free hydrochloric acid.
  - Enzymes
    - Pepsin.
    - Rennin.
    - Gastric lipase.
  - Inhibited by
    - Stimulation of sympathetic system, anger, pain, fear, worry, distaste for food.
    - Secretion dependent on blood, hence checked if blood-supply is diverted.

Hydrochloric Acid

- Secreted by parietal cells of gastric glands from chlorids found in blood.
- NaCl most abundant—Cl (chlorin) combines with H (hydrogen) to form HCl (hydrochloric acid).
- Normal proportion about 0.2 per cent.
- **Functions**
  - Activates pepsinogen and converts it to pepsin.
  - Provides acid medium for pepsin to carry on its work.
  - Swells protein fibers.
  - Helps in inversion of cane-sugar, easiest disaccharid to invert.
  - Acts as a disinfectant and kills bacteria.
  - Helps to regulate opening and closing of pyloric valve.

Pepsin

- Formed in pyloric glands and chief cells of gastric glands.
- Pepsinogen—zymogen, changed by HCl to active pepsin.
- Weak proteolytic enzyme—requires acid medium.
- Hydrolyzes proteins through several stages to proteoses and peptones, which action is preparatory to more complete hydrolysis in intestine.

Rennin

- Formed in chief cells of gastric glands.
- Prorennin—zymogen—secretin converts to active enzyme.
- Acts only upon caseinogen, converts it to curd, preparatory to further action by pepsin and trypsin.

Gastric lapse—Limited action on emulsified fats like cream.

Functions of Stomach

- Serves as temporary storage reservoir.
- Contractions promote mechanical reduction of food.
- Salivary digestion continues until acidity is established.
- **Gastric digestion**
  - Pepsin hydrolyzes proteins.
  - Rennin hydrolyzes caseinogen.
  - Gastric lipase may hydrolyze emulsified fats.
- HCl has germicidal action—hence stomach serves as disinfecting station.

Intestinal Digestion

- Definition—changes the food undergoes in the small and large intestine.
- **Small Intestine**
  - **Movements**
    - Peristaltic — pushes food forward slowly.
    - Rhythmic segmentation breaks food up into small particles, facilitates mixing with intestinal secretions.
  - **Secretions**
    - Pancreatic fluid.
    - Succus entericus.
    - Bile.
  - **Bacteria**
    - Decompose carbohydrates.
    - Little or no effect on protein.
  - **Time required**
    - Depends on proportions of different foodstuffs.
    - Food begins to pass into large intestine from 2 to 5¼ hours after eating, requires 9 or more hours before last of meal has passed.

Intestinal Digestion

- **Large Intestine**
  - **Movements**
    - Mass peristalsis moves food from one division to another.
    - Constant rhythmic contractions.
  - Secretion—contains mucin—no enzymes, alkaline reaction.
  - Digestive enzymes from duodenum continue to act.
  - **Bacteria**
    - Hydrolysis of proteins constant.
    - Possible action on cellulose.
    - Benefit doubtful.

Pancreatic Fluid

- Secretion controlled by hormone secretin. Discharged into small intestine during digestion.
- Clear, viscid fluid, alkaline reaction.
- **Enzymes**
  - **Trypsin**
    - Secreted in form of zymogen—trypsinogen—activated by enterokinase, an enzyme contained in mucous membrane of small intestine.
    - Hydrolyzes proteins—action rapid and powerful — if complete hydrolysis occurs, end-products are amino-acids.
    - Active in slightly acid, neutral, or strongly alkaline media.
  - **Amylase or Amylopsin**
    - Action similar to ptyalin.
    - Hydrolyzes starch to achroadextrin and maltose.
  - **Lipase or Steapsin**
    - Hydrolyzes fats to glycerin and fatty acids.
    - Emulsification depending on saponification occurs as soon as small amount of fat is split to fatty acids and glycerin.
    - Fatty acid combines with alkaline salts to form soaps. Hence emulsification regarded as preparatory process.
    - Action is reversible—synthesizes fatty acids and glycerin to form fat, characteristic of human animal.

Succus Entericus

- Secretion thought to be promoted by secretin.
- Clear yellowish fluid alkaline reaction, contains mucin.
- Disagreement regarding functions—intracellular enzymes credited with share in work of digestion.
- **Enzymes**
  - Enterokinase—activates trypsinogen.
  - Erepsin—hydrolyzes proteoses and peptones to amino-acids.
  - Maltase—hydrolyzes dextrin and maltose to dextrose.
  - Invertase—hydrolyzes sucrose to dextrose and levulose.
  - Lactose—hydrolyzes lactose to dextrose and galactose.
  - Nuclease—acts upon nucleic-acid portion of nucleoproteins.
- Hormone—Secretin—exists in cells in form of prosecretin, changed by acid to secretin.

Bile

- Alkaline liquid, color may be golden yellow, green, brown.
- Amount secreted varies with amount of food eaten, estimated about 500 to 800 cc. daily.
- Consists of water, inorganic salts, bile-salts, lecithin, cholesterin pigments and nucleo-albumin.
- Bile-salts, *i.e.*, sodium taurocholate and sodium glycocholate, thought to stimulate activity of the liver.
- Secreted continuously, enters duodenum during period of digestion.
- Probably contains coenzymes and activates pancreatic lipase.
- Digestive action—serves as a coenzyme and activates lipase.
- Excretion—eliminates products of disintegration of hemoglobin.
- Antiseptic—thought to limit putrefaction.
- **Abnormal conditions**
  - Jaundice—due to absorption of bile by blood—carried throughout body—pigments deposited in skin and whites of eyes.
  - Gall-stone—accretions of solid matter precipitated from bile. Formed in gall-bladder, also cystic and hepatic ducts.

Feces

- Composition and amount depend on character of food.
- Undigested and indigestible portions of food.
- Products of bacterial decomposition, *i.e.*, indol, skatol, and fatty acids.
- Great quantities of bacteria.
- Bile and other secretions.
- Some of the purin bases and inorganic salts.
- Color due to pigments derived from bile.

Defecation—term applied to the fact of expelling feces from rectum.

CHAPTER XIX

ABSORPTION OF FOOD FROM THE ALIMENTARY CANAL.—METABOLISM OF CARBOHYDRATES; METABOLISM OF FATS; METABOLISM OF PROTEINS

By absorption is meant the passage of digested food material from the cavity of the alimentary canal to the blood. Though food may be digested and ready for nutritive purposes, it is practically *outside of the body* until it passes through the walls of the alimentary canal.

Paths of absorption.—There are two paths by means of which the products of digestion find their way into the blood:—

(1) By the capillaries in the walls of the intestines.

(2) By the lymphatics in the walls of the small intestine (the lacteals).

Absorption takes place chiefly from the small intestine. The reasons for this are: (1) very little of the food is sufficiently digested to be absorbed before it reaches the duodenum; (2) the circular folds of the small intestine and the villi covering the surface of these folds, (*a*) delay the food, (*b*) increase the surface and (*c*) provide a maximum number of capillaries and lacteals for absorption; (3) the muscular movements of the small intestine press the contents against the villi, and thus favor absorption (4) it is thought that the cells of the mucous membrane of the intestine exert a selective action.

Absorption in the stomach.—Absorption does not take place readily in the stomach. The results of many experiments indicate that the sugar resulting from the digestion of starch by ptyalin is passed on to the intestines for further digestion. Little or no absorption of digested proteins occurs. Fats are probably not digested in the stomach. Under ordinary conditions the dilute solutions of inorganic salts are not absorbed. Water and saline solution are not absorbed, but pass into the duodenum. This is true even when large amounts of fluid have been lost from the body, and extreme thirst is present. When there is stricture or paralysis of the pylorus, or lack of tone of the muscular walls of the stomach (as often happens after an individual has been kept under a general anesthetic for some time), the introduction of water into the stomach causes distention, often followed by vomit-

ing. Alcohol, mustard, pepper and other condiments appear to be absorbed from the stomach.

Absorption in the large intestine.—When the contents of the small intestine pass the colic volve they still contain a certain amount of unabsorbed food material, and due to the contained enzymes digestion and absorption continue. The consistency is about that of chyme. This is possible because the absorption of water in the small intestine is compensated by the secretions which pour into it. In the large intestine the absorption of water is marked, sufficiently so under usual conditions to cause the formation of semi-solid or hard feces.

Water.—As previously stated the stomach does not allow an appreciable amount of water to be absorbed. In the small intestine large quantities are absorbed, but this loss is made good by osmosis or secretion of water into the intestine. It is in the large intestine that the most marked absorption takes place.

Inorganic Salts.—The absorption of salts from any part of the intestines depends upon (1) the concentration of the solution, and (2) the nature of the salt. When salts are in a hypotonic[1] solution, absorption is more rapid than when they are in a hypertonic solution. In addition certain salts are readily absorbed, *i.e.*, acetates, chlorids and most of the ammonium salts; on the other hand, tartrates, citrates, calcium salts, and some of the sulphates, are not absorbed even when in dilute solutions. The reason is that the latter inhibit the absorption of the water in which they are dissolved and thus increase the bulk of the intestinal contents. For this reason such salts act as cathartics.

Standard substances.—The standard substances resulting from digestion are: (1) simple sugars, derived from the various carbohydrates, (2) fatty acids and glycerin, derived from the various fats, and (3) amino-acids, derived from the various proteins.

(1) The simple sugars pass into the capillaries and thence by way of the portal tube to the liver.

(2) The fatty acids and glycerin are absorbed as such in the small intestine. During their passage through the intestinal walls the fatty acids and glycerin recombine to form simple fats. It is believed that this synthesis is due to the action of lipase, the same enzyme which splits fats into their component parts. Hence the action of lipase is said to be reversible. The greater part of the fat is absorbed by the lacteals in the villi and carried to the great

[1] See page 398.

thoracic duct which empties into the left subclavian vein. In addition it is considered probable that some of the fat is absorbed directly by the capillaries of the villi, and carried by way of the portal tube to the liver, before reaching the general circulation.

(3) The amino-acids pass into the capillaries of the villi. There is increasing evidence that amino-acids are found in the blood, and are distributed by the blood to the tissues.

Process of absorption.—The process of absorption consists of (1) active absorption and (2) passive absorption.

(1) The lining of the intestine is a living membrane composed of cells arranged side by side. The products of digestion must pass through these cells in order to reach the blood and lymph. Normally this membrane is semipermeable, *i.e.*, it allows some substances to pass, and will not allow others. The question arises —in what way is the passage of the digested foodstuffs effected? Do these cells exert a selective action, or do they permit them to pass in accordance with physical laws? The consensus of opinion seems to be that while the laws of diffusion and osmosis play an important part, the lining cells serve as minute laboratories and are able to force the nutritive substances through their cytoplasm in an active way. Consequently these cells are comparable to glands with this difference, that they select substances from the contents of the intestinal canal and transfer them to the blood or lymph-channels. In addition these cells are able to synthesize the glycerin and fatty acids into fat.

(2) The physical laws of diffusion, osmosis, and dialysis, play an important part in absorption. (*a*) If a solution of salt is placed in a receptacle and a layer of water poured over it, some of the molecules of salt will pass up into the superimposed water, and after a time the total amount of solution will be of uniform composition. Such an interchange would also occur if two solutions of different salts were brought into similar relations with each other. This is called *diffusion*, *i.e.*, the spreading or scattering of molecules through suitable media. (*b*) If the solution of salt and the water are separated by a membrane permeable to the molecules, water molecules will pass through the pores of the membrane to the salt solution, thereby raising the level of the latter. This passage of the water from one side of the membrane to the other in response to the difference in concentration of the fluids is called *osmosis*, and the pressure exerted against the membrane is called osmotic pressure. (*c*) If a solution of (unboiled) white of egg and salt is placed on one side of a membrane

and water placed on the other side, the salt molecules will pass over to the water, and leave the white of egg practically undiminished in amount. The process by which diffusible salts separate themselves from substances which cannot ccompany them through membranes is called *dialysis*. In the passage of material from the lumen of the intestine these laws operate to a limited extent. Crystalline substances such as salts and sugars are more readily absorbed when in dilute rather than in concentrated solutions, and concentrated solutions favor the passage of water from the tissues and vessels into the lumen of the tube. However, these processes do not account for the marked difference in the degree to which different substances are absorbed.

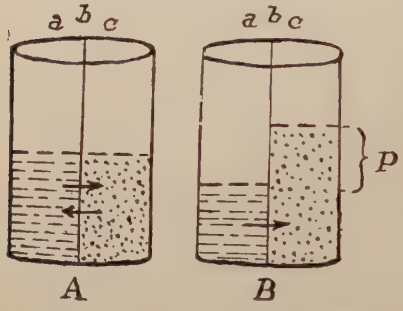


FIG. 206.—DIAGRAM TO ILLUSTRATE OSMOSIS. *A*, chamber containing water; *B*, chamber containing a solution of salt; *b*, membranous partition between the two chambers. In *A*, *b* is permeable to all the substances; in *B*, *b* is semipermeable—impermeable to the salt molecules, but permeable to the water molecules. *P*, difference of level of the liquids when the chambers are separated by a semipermeable membrane, measures the osmotic pressure.

A solution possessing the same concentration and osmotic pressure as the blood, is said to be *isotonic*. A solution of greater concentration and higher osmotic pressure is *hypertonic*, and one of lower concentration and lower osmotic pressure is *hypotonic*.

METABOLISM

General metabolism includes all the processes involved from the time food enters the body until it is excreted.[2] But ordinarily the use of the term is limited to include only the changes that occur in digested foodstuffs from the time of their absorption until their elimination in the excretions. This includes all the chemical activities that take place within cells. It is in this latter way that it is used in this chapter.

[2] This is outlined as follows:—

- **Metabolism**
  - Anabolic
    - Ingestion.
    - Digestion.
    - Absorption.
    - Assimilation.
  - Catabolic
    - Dissimilation.
    - Excretion.

Metabolic changes.—The changes constituting metabolism can be classified under two heads: (1) **anabolism,** or constructive processes, and (2) **catabolism,** or destructive processes.

(1) The changes classified as anabolic or anabolism consist of the processes by which living cells take food substances from the blood, and make them a part of their own protoplasm. This involves the conversion of non-living material into living material and is a building up or synthetic process. Comparatively little is known of the nature of anabolic changes, but it is thought they are largely of the dehydration type, which is the opposite of hydrolysis, and consists of the putting together of molecules with a loss of water.

(2) The changes classified as catabolic or catabolism consist of the processes by which living cells disintegrate into simpler substances; (*a*) part of their own protoplasm, or (*b*) substances which have never been incorporated in their own protoplasm. This disintegration yields simpler substances, some of which may be used by other cells, though most of them are excreted. The catabolic processes consist mainly of (1) the simple splitting of complex molecules into smaller ones, (2) hydrolysis, *i.e.*, the splitting of complex molecules into simpler ones with the absorption of water, and (3) oxidation or the union of oxygen with the constituents of the cells.

Functions of metabolism.—Metabolic changes serve two important purposes: (1) the growth and repair of tissue, and (2) the release of energy in the form of heat, nervous activity, muscular activity, etc.

Factors which promote metabolic changes.—The factors which promote metabolic changes are: (1) oxygen absorbed from the lungs, (2) enzymes secreted by the tissue cells, (3) autacoids secreted by the ductless glands, (4) vitamins furnished by food and (5) the nervous system.

METABOLISM OF CARBOHYDRATES

It is convenient to consider the history of carbohydrates under three heads: (1) its supply; (2) its storage; and (3) its consumption.

(1) The supply is regulated by the diet.

(2) The storage is provided for temporarily by the liver, the muscles, and the cells of all tissues.

During the process of digestion all the carbohydrates are changed to simple sugars. It is possible that a small amount of

sugar is absorbed in the stomach, but by far the greater part passes into the capillaries of the small intestine. These capillaries pour their contents into the portal tube, which carries the blood rich with glucose to the liver. The liver cells take this glucose from the blood, and by putting together a number of molecules and withdrawing water[3] the soluble glucose is changed to insoluble glycogen, which is stored in the liver cells. In thus storing up glycogen and doling it out as needed, the liver helps to maintain the normal quantity of glucose—0.07 to 0.1 per cent—in the blood. If the glucose were left in the blood in larger amounts than 0.1 per cent it would be eliminated in the urine and the body would thus lose its main fuel supply. From the blood-stream glucose is taken up by the muscles and other tissues and stored as glycogen until needed. Hence the liver serves as a central storehouse from which the tissues receive their supply whenever their content of glycogen is depleted. The percentage of sugar in a muscle cell is small, though their total content equals that of the liver. The maximum storage of glycogen in the body is about ten ounces (300 gms.). The conversion of glycogen into glucose as it is required by the tissues is effected by glycogenase an enzyme contained in the liver cells. The need of the blood for glucose is constant, because it is constantly giving up glucose to the tissues.

(3) At the consumption end the amount of sugar oxidized is controlled by the energy needs of the tissues, particularly the muscles, for their activity is the principal factor determining the rate of oxidation, and naturally the amount of fuel required will be in proportion to the rate at which it is used. At least two enzymes are essential for the catabolism of sugar: (*a*) cleavage (hydrolytic) enzymes which promote the primary splittings, and (*b*) oxidizing enzymes or oxidases which stimulate the oxidation of the cleavage products. The activity of these enzymes is thought to be influenced by insulin, the hormone of the internal secretion of the pancreas.

Regulation of blood sugar.—The way in which the amount of glucose in the blood is regulated is not known, but it is thought to be under the control of the central nervous system, and this in turn is influenced by the amount of sugar in the blood, and also the amount of epinephrin. Under conditions of emotional excitement, sugar is excreted in the urine and this is supposed to be due to reflex stimulation of the adrenals, and consequent increase of epinephrin in the blood, which in turn increases the

[3] This is a process of dehydration and is exactly the opposite of hydrolysis.

output of sugar from the liver. Insulin, the hormone of the internal secretion of the pancreas, reduces the amount of sugar in the blood by altering the character of the glucose and thus rendering it more available for consumption by the tissues.

Functions of carbohydrates.—The oxidation of glucose serves the following purposes: (1) It furnishes the main if not the only source of energy for muscular work, and for all the nutritive processes of the body. The glycogen of a muscle disappears in proportion to the work done by the muscle, and it is believed that the oxidation of the sugar furnishes the energy which is utilized by the muscles to do work. (2) It furnishes an important part of the heat needed to maintain the body temperature. Each gram of sugar on oxidation yields four Calories of heat, and since the carbohydrates form the largest part of our diet, and are easily oxidized, they must be regarded as specially available material for keeping up animal heat. (3) It prevents oxidation of the body tissues, because it constitutes a reserve fund that is the first to be drawn upon in time of need. As carbohydrate food is increased, protein food may be diminished down to a certain irreducible minimum, which is probably the amount necessary for the reconstruction of new tissue. (4) An excess of carbohydrates over and above what can be stored as glycogen in the liver and muscles is converted into adipose tissue. Nutritional experiments leave no doubt that the fat of the body may be formed from carbohydrate food. (5) To some extent carbohydrates may be used in constructive processes. The evidence in support of this statement is incomplete, but the fact remains that a carbohydrate group forms part of some protein molecules, and *lactose*, a carbohydrate, is a normal constituent of the milk secreted by the mammary glands.[4]

Waste products of carbohydrate metabolism.—The waste products resulting from the oxidation of glucose are carbon dioxide (CO_2) and water (H_2O). This process is thought to be comparable to the fermentation of sugar outside the body, and the same substances are formed, *viz.*, alcohol, acids, carbon dioxide and water.

Derangements of carbohydrate metabolism.—The sugar regulating mechanism of the body may prove inadequate in one of four ways:

(1) Conversion of sugar to glycogen in the liver (glycogenesis) breaks down, giving rise to alimentary glycosuria, *i.e.*, sugar in

[4] See page 516.

the urine. This may follow the ingestion of a larger amount of sugar than the liver and muscles can store, resulting in an increased amount in the blood (hyperglycemia). A higher percentage of sugar than normal (0.07 to 0.1 per cent) in the blood is irritating to the tissues, and the sugar is excreted in the urine. This is designated as temporary glycosuria.

(2) Conversion of glycogen to sugar in the liver (glycogenolysis) breaks down in injuries to the central nervous system, excessive internal secretion by suprarenal glands, etc.

(3) The consumption of sugar in the tissues for energy purposes (glycolysis) breaks down in pancreatic diabetes and diabetes mellitus. Removal of the pancreas of an animal is followed by the appearance of sugar in the urine in large amounts. If the extirpation is complete glycosuria is followed by emaciation and muscular weakness, which finally end in death in two or three weeks. On the other hand, if a portion of the pancreas is left, even though its connection with the duodenum is interrupted, it may prevent glycosuria partly or completely. This indicates that the internal secretion is the important factor in the metabolism of sugar.

(4) The normal impermeability of the kidney breaks down in phlorizin diabetes. Phlorizin is obtained from the roots of certain trees, such as apple and pear. When injected into an animal it causes a temporary glycosuria, which is very complete.[5] as long as the action of the drug lasts. The action of phlorizin has not been satisfactorily explained, but it seems that the drug acts on the kidney itself.

Diabetes mellitus.—In mankind derangements of carbohydrate metabolism manifest themselves chiefly in the disease known as diabetes mellitus. In this disease the daily loss of sugar in the urine may be very large. In severe cases all the carbohydrate of the food may be excreted in the form of sugar, and even when no carbohydrate food is eaten, sugar continues to be excreted in considerable amounts. In the latter case the sugar is supposed to have its source in the proteins of the food or of the tissues. The symptoms of diabetes mellitus in man closely resemble the symptoms of pancreatic diabetes in dogs. The opinion of experts in this field is that a lesion in the islands of Langerhans in the pancreas results in a reduction of the supply of insulin to the body and in consequence the tissues cannot use the sugar brought to them by the blood. In addition to the sugar found

[5] Sugar eaten and sugar formed in body are secreted.

in the urine in diabetes, this secretion may contain considerable amounts of the acetone bodies. These acetone bodies are intermediary products in the metabolism of fats, and their presence is due to incompleteness in the normal processes of the oxidation of fat. There is no satisfactory explanation of the relationship between the loss of power to metabolize sugar and incomplete oxidation of fats. The accumulation of acetone bodies in the blood and tissues of the diabetic is responsible for the production of *acidosis*.

METABOLISM OF FATS

The results of experimental work confirm the view that after fat is split into glycerin and fatty acids, it is absorbed by the epithelial cells of the villi and reconstructed in the very act of passing through them. This fat passes into the lacteals of the villi. From these small lacteals it must find its way through the larger lymphatics in the mesentery to the thoracic duct, and then through the thoracic duct to the blood. This fat is carried by the blood to all the different parts of the body, and the tissues slowly take it out as they need it in their metabolic processes. Within the tissues it serves as fuel and is oxidized to supply the energy needs of the cells. If fat is burned outside the body, heat is liberated, and the waste products are carbon dioxide and water. This process is similar to the one that takes place in the body.

Factors controlling metabolism of fats.—It is thought that the catabolism of fats is brought about by some enzyme furnished by the tissue cells or a hormone from one of the ductless glands. It is also dependent in some way upon the oxidation of glucose, and when this is interfered with as in severe cases of diabetes, the fats are incompletely oxidized and acetone bodies are produced. An accumulation of these acid bodies is responsible for the acidosis and diabetic coma which occur in advanced stages of diabetes.

Functions of fat.—The uses of fat are (1) to serve as fuel and yield heat and other forms of energy. From a chemical standpoint fats contain more available energy weight for weight than the proteins or the carbohydrates. (2) It may be stored in the tissues as part of the body fat. (3) It may be synthesized with other substances to form some more complex constituent of the body, such as lecithin.[6] Normally the blood contains about 0.7 per cent of fat, but during the digestion of food containing a high

[6] A complex fat containing phosphorus and nitrogen.

percentage of fat this amount may be temporarily increased. The highest fat content of the blood is reached about six hours after a meal. It drops to normal rather rapidly so that some physiologists think there must be special places, for the rapid storage of excess fat. In time of need, the available glycogen is oxidized, and then this fat is drawn upon. If the supply of glycogen and fat is not sufficient, the other fatty tissues contribute their fat for oxidation. In this way fat protects the proteins of the body.

Derangements of fat metabolism.—When fat is fully oxidized the only end-products are carbon dioxide and water. In certain diseased conditions, for instance, severe diabetes, the oxidation of fat is incomplete, and certain compounds of an acid character are formed.

The cause of obesity.—This condition is usually caused by eating more food than the body needs, especially fat and carbohydrates. The excess is stored as glycogen and adipose tissue. The needs of different individuals vary, depending on their mode of life, and on their capacity to oxidize food materials, so that a diet which will give an excess to one individual may in the body of another be entirely consumed. A sedentary life and absence of worry lessen the oxidation of food products and increase the tendency to take on flesh, while a very active muscular life has the opposite effect.

METABOLISM OF PROTEINS

As a result of digestion, proteins are hydrolyzed to amino-acids, and are absorbed by the blood capillaries of the villi. From the intestines this blood passes through the liver before it reaches the general circulation and it is a question whether amino-acids are acted upon in any specific way by the liver. After a meal the amount of amino-acids in the blood and tissues is increased, and this is interpreted by some as evidence that the amino-acids pass through the liver without undergoing any change. They are carried to all parts of the body, and are used (1) during the period of growth to build up new tissues; and (2) both in youth and after growth has ceased, to replace tissue that has been oxidized. It is probable that we eat more protein than is needed for tissue building, and the amino-acids in excess of what are needed for this purpose are utilized as a source of energy. They are deaminized, *i.e.*, the amino radicles (NH_2) are removed.

This nitrogenous portion passes through a series of changes and is converted to urea $CO(NH_2)_2$ which is of no further use in the body and is removed from the blood by the kidneys. The non-nitrogenous product of deaminization seems to have a history similar to that of carbohydrate. It is oxidized to furnish energy, or is built into sugar or fat, and oxidized later. It was formerly taught that the process of deaminization was accomplished mainly in the liver. It is now thought that it takes place in the body generally, and that the liver shares in this activity.

Classification of protein metabolism.—The types of protein metabolism are classified as *endogenous* and *exogenous*. Under the head of *endogenous* are included the various steps in the history of the amino-acids which are built up into the proteins of the tissues and blood, as well as the eventual disintegration of these proteins. The end-products of this disintegration found in the urine are urea and creatinin. The urea rises and falls with the protein ration, but the creatinin[7] is influenced little by variations in diet. Therefore it is believed that endogenous metabolism is relatively independent of food, at least while nutrition is satisfactory. *Exogenous* metabolism includes all the reactions affecting the uncombined amino-acids. It includes the formation of urea from the nitrogenous portion of the deaminized amino-acids, and the glucose formed from the non-nitrogenous portion. It also includes the secondary production of glycogen or fat from surplus sugar originating in this way. In contrast with endogenous metabolism it varies widely.

In the classification of proteins given on page 367 it was stated that one of the conjugated proteins was nucleoprotein. In the course of digestion the protein is separated from the nucleic acid and is eventually reduced to amino-acids. The nucleic acid give rise to substances known as purin bodies.[8] Uric acid is the end-product of the metabolism of purin bodies, from which it arises. as a result of oxidation. Foods rich in nucleoproteins are sweetbreads, kidney, roe, liver and sardines. Foods with a fairly high nucleoprotein content are beef, veal, mutton, pork, chicken, turkey, goose and other game, fish (cod excepted), spinach, asparagus, and beans. Nucleoproteins are also found in the nuceli of the cells of the body. Consequently oxidation of the protein material of the body gives rise to amino-acids, and nucleic acid, which is reduced to uric acid. Uric acid resulting

[7] See page 427.
[8] See page 428.

from the oxidation of the nucleoproteins of food is classed as exogenous. Uric acid resulting from the oxidation of the nucleoproteins of the body tissues is classed as endogenous.

Nutritive value of different proteins.—Proteins vary in their constituents and in their nutritive value. Because of this they are classed as adequate and inadequate proteins. *Adequate* proteins contain all the constituents for the growth and maintenance of the body. *Inadequate* proteins furnish material for energy needs, but not for growth and the repair of tissue waste. The difference between the two kinds seems to lie in the character of the amino-acids of which they are composed. Gelatin is an example of an inadequate protein. It is easily digested and absorbed, undergoes oxidation, which results in the liberation of energy and the production of urea, carbon dioxide, and water, but it does not supply the material needed for the repair of tissue waste. On the other hand, the casein of milk and the glutenin of wheat contain all the essential amino-acids and not only furnish energy, but can build tissue.

Nitrogen equilibrium.—The nitrogenous portion of the protein molecule is not stored in the body but is eliminated chiefly in the urine, and to a limited extent in the feces. The body is said to be in nitrogen equilibrium when the amount of protein nitrogen taken into the body is equal to the amount eliminated in the excreta. If there is a plus balance in favor of the food, it means that protein is being stored in the body, and this is an ideal condition during the period of growth or convalescence from wasting illness. If the balance is minus, it means that the body is burning its own protein to supply its needs.

Specific dynamic reaction of proteins.—This term refers to the fact that proteins speed up the metabolic processes of the body to a greater extent than fats or carbohydrates do. When the latter are fed in excess of immediate needs, the extent to which they are used by the body is largely determined by the amount of exercise and the heat production. When proteins are fed they are largely destroyed irrespective of the energy needs of the body. A comparison of the effects of proteins, carbohydrates and fats in respect to the increase in the metabolic rate show that proteins (heavy meat diet) may increase this rate as much as 90 per cent, whereas carbohydrates and fats may cause an increase of 30 to 40 per cent.

Quantity of food.—The foods taken into the body are the source of energy either for tissue building or work. This energy

is made available by the chemical changes which occur during digestion and metabolism. Metabolic changes release energy, and in this case we may think of energy release as heat production. The production of heat varies with many factors, and many efforts have been made to determine what is the normal heat production, so that a standard would be available by which abnormalities could be judged. The heat or energy production necessary to keep the body alive, *i.e.*, to sustain its warmth, to maintain muscle tone, and the vital activites such as breathing, digestion, heart action, etc., has been called *basal metabolism*.[9] Over and above the food required to meet the needs of basal metabolism, which represents the bare necessities, some energy is expended in working over the daily food, and this is described as the *cost of digestion*. Still a third factor is represented by the energy required for work, and this is subject to very wide variations. Consequently the daily intake of food should be sufficient to meet the sum of these three needs. The foods which yield energy are carbohydrates and fats. Proteins are tissue builders, although the non-nitrogenous portion of the amino-acid may be converted to glycogen, and serve for energy purposes just as carbohydrates and fats do. To determine the amount of energy in any given food, it is burned and the amount of heat given off is noted. It matters little whether the burning occurs in a test tube or in the living body. The heat produced is measured in terms of Calories by means of a calorimeter. A large Calorie (Cal.) is the amount of heat required to raise one kilogram (2.2 lbs.) of water 1° C, or one pound of water 4° F. The large Calorie (Cal.) is the one referred to in physiology. As the result of many tests the caloric value of the different foodstuffs to the body has been found to be as follows:[10]

Carbohydrate	1 gm.	= 4 cal.
Fat	1 gm.	= 9 cal.
Protein	1 gm.	= 4 cal.

In order to provide energy for basal metabolism, the cost of digestion, and for work, it is necessary to consider age, activity and in lesser degree, size, shape, body composition, lactation, and climate. The greater the amount of muscular work, the greater

[9] For discussion of basal metabolism see Chemistry of Food and Nutrition by Sherman, H. C., chapter VII in second edition; also Basal Metabolism in Health and Disease by Du Bois, Eugene F., chapter VI.

[10] These figures are lower than those usually given, *e.g.*, carbohydrate 4.1, fat 9.3, and protein 4.1, which are known to allow too little for losses in digestion.

the amount of food required. Children need more food in proportion to their weight than adults, because they are more active internally and externally, and in addition must provide for the growth of new tissue. Increased age usually means less active life as well as less active metabolism and thus less food is required. Women, as a rule, require less food than men, because they have somewhat less active tissue in proportion to weight, and tend to more sedentary life. In an extremely cold climate more food is required for heat production in order to make up for the loss of heat from the body. It is ordinarily estimated that the daily diet should yield between 2450 and 2800 Calories for an individual weighing 70 kilograms (154 lbs.); that is, about 40 Calories for each kilogram of body weight. Various authorities recommend that ten to fifteen per cent of the daily Calories should be in the form of protein. When the protein in the diet is excessively high it raises the metabolism without any beneficial effect, and possibly harmful effects. It is at least a wasteful excess and should be avoided. On the other hand, while it is possible to satisfy the nitrogen requirements with less than ten per cent of protein, such a supply does not afford much reserve for such emergencies as loss of digestion, or inability of the body to utilize to good advantage the type of protein supplied, hence it is usually inadvisable.

The amount of fat which can be digested varies with different individuals but the average man's maximum capacity for the digestion of fat is about 200 grams per day, and 75 grams seems essential. Within these limits much variation is possible. The amount of carbohydrates which can be taken to advantage depends upon the form, starch being capable of good digestion up to 500 grams per day. The assimilation for sugar varies with the kind, but is lower than for starch. In the ordinary diet of a healthy individual the carbohydrates tend to predominate, so that there is seldom necessity for estimating fat and carbohydrate separately.[11]

Flavors and condiments.—The most important service rendered by these bodies is that by making the food appetizing they increase the secretion of gastric fluid.

Stimulants.—Under this heading is included tea, coffee, cocoa, and meat extracts. Tea and coffee owe their stimulating action to caffein. Cocoa, or the chocolate made from it, contains nour-

[11] For a more complete discussion of this subject consult—A Laboratory Handbook for Dietetics. Revised Edition by Rose, M. S.

ishment in the form of carbohydrate, fat, and protein. Its stimulating effects are due to theobromin, and are similar to those of caffein. Meat extracts contain secretagogues which stimulate the gastric glands to secretion, but aside from this have little nutritive value.

Alcohol.—Alcohol is rapidly absorbed and quickly oxidized. It yields heat, and gives rise to carbon dioxide and water. It is not transformed into fat or glycogen, hence is not stored. Indirectly it may cause obesity in two ways: (1) moderate drinking creates a keen appetite and so favors overeating; (2) the oxidation of alcohol lessens the need for the oxidation of fats or carbohydrates. Thus fat is spared to be accumulated, or carbohydrates to be changed into it.

Foods to regulate body processes.—Experimental work with animals has demonstrated that a sufficient number of Calories representing the proper proportion of proteins, carbohydrates, and fats may lack other essentials necessary for the maintenance of health. These essential substances are ash constituents, vitamins, and water. The most important ash constituents are derived from phosphorus, iron, calcium, sulphur, magnesium, potassium, sodium, iodin, and chlorin. There is abundant evidence that attention must be paid to the mineral elements of the diet, some of which are as indispensable as protein, even though needed in small amounts. The ones which it seems most unwise to leave to chance are calcium, iron, and phosphorus, because diets which supply adequate amounts of protein and fuel do not always carry enough of these. Generally diets having enough calcium and iron will supply sufficient phosphorus. Usually it is simpler to see that the foods rich in these elements are represented in the diet. They are milk, egg, whole grains, peas, beans, green vegetables and fruits. If there is a scarcity of the above foods or a diet rich in some particular ash constituent is desired, quantitative estimates of the various elements can be made by using tables such as are found in standard text-books on dietetics. Numerous experiments by eminent workers[12] prove definitely that not only do specific diseases develop, but malnutrition of all grades occurs where vitamins[13] are not present in sufficient amounts. It is impossible[14] to state definitely how much of each of the three known vitamins is required either for adults or

[12] Osborn, Mendel, Funk, Vedder, Takaki, McCollum and his co-workers.

[13] See page 368.

[14] Scientific investigation has shown the need for vitamins, but has not gone far enough to determine the amounts needed.

children. On a diet which meets all other nutritive requirements, and in which milk, vegetables, and some fresh food (*i.e.*, fruits or green vegetables) are a required part of the menu, there is little likelihood of deficiency in any of the vitamins.

Sufficient *water* is needed to make good the amount lost from the tissues, and for the various other purposes that water serves in the body.[15] It is estimated that one glassful on rising in the morning, one glassful with each meal, one between each meal and one before retiring are essential.

SUMMARY

Absorption

Passage of digested food material from the cavity of the alimentary canal to the blood.

Paths of absorption

1. Capillaries in the walls of the intestines. This blood is carried by means of portal tube to liver, from liver by hepatic veins to inferior vena cava, thence to right auricle.
2. Lymphatics in the walls of small intestine (lacteals) absorb digested fats and empty into chyle cistern of thoracic duct, superior vena cava, and right auricle of heart.

Occurs

Stomach—very limited. Alcohol, pepper, mustard and other condiments appear to be absorbed.

Small intestine—marked—due to

1. Food sufficiently digested to be absorbed.
2. Circular folds and villi, delay food, increase surface, and provide maximum number of capillaries and lacteals.
3. Muscular movements favor absorption.
4. Cells exert a selective action.

Large intestine—limited absorption of digested foodstuffs, marked absorption of water.

Place of Absorption of Digested Foodstuffs

Water—absorbed in small intestine, but loss made good by secretion, marked absorption in large intestine.

Salts—absorption may take place from any part of intestines, depends upon the concentration of the solution, and the nature of the salt.

Simple sugars—pass into capillaries and then by way of the portal tube to the liver.

Fatty acids and glycerin—absorbed by lacteals in the villi synthesized to form fat, and fat is carried to great thoracic duct, which empties into left subclavian vein.

Amino-acids—pass into capillaries of villi.

[15] See page 362.

Process of Absorption

- Active process due to selective action of cells of lining membrane of intestinal canal. Cells serve as minute laboratories—synthesize glycerin and fatty acids to fat.
- Passive process due to physical laws of (1) diffusion, *i.e.*, the spreading or scattering of molecules through suitable media; (2) osmosis, the passage of water from one side of a permeable membrane to the other in response to differences in concentration of fluids on either side; and (3) dialysis, the process by which diffusible salts separate themselves from substances which cannot accompany them through membranes.

Solutions

- Isotonic—same concentration and osmotic pressure as blood.
- Hypertonic—greater concentration and higher osmotic pressure then blood.
- Hypotonic—lower concentration and lower osmotic pressure than blood.

Metabolism

- Refers to changes that occur in foodstuffs from time of absorption to elimination.
- Includes the chemical activities that take place within cells.
- **Consists of**
  - Anabolism—processes by which living cells take food substances from the blood and make them a part of their own protoplasm.
  - Catabolism—processes by which living cells disintegrate into simpler substances, (*a*) part of their own protoplasm, or (*b*) substances which have never been incorporated in their own protoplasm.
  - Catabolism consists of
    1. Simple splitting of complex molecules into simpler ones.
    2. Hydrolysis or the splitting of complex molecules into simpler ones with the absorption of water.
    3. Oxidation or the union of oxygen with the constituents of the cells.
- **Functions**
  - Growth and repair of tissue.
  - Release of chemical energy in the form of heat, nervous activity, muscular activity, etc.
- **Factors**
  1. Oxygen absorbed from lungs.
  2. Enzymes secreted by tissue cells.
  3. Autacoids secreted by the ductless glands.
  4. Vitamins furnished by the food.
  5. The nervous system.

Metabolism of Carbohydrates

- **History**
  1. Supply regulated by diet.
  2. Storage provided for temporarily by liver, muscles, and cells of tissues. Simple sugars stored as glycogen.
  3. Consumption controlled by the energy needs of the tissues.
- **Enzymes**
  - Catabolism of sugar dependent on:
    1. Cleavage (hydrolytic) enzymes, and
    2. Oxidizing enzymes.
  - Activity of these enzymes thought to be influenced by insulin the hormone of the internal secretion of the pancreas.

Metabolism of Carbohydrates

- **Regulation of blood-sugar**
  1. Under control of nervous system.
  2. Influenced by amount of sugar and epinephrin in blood.
  3. Influenced by emotional excitement.
  4. Insulin alters character of glucose so that tissues can use it.
- **Functions**
  - Furnish main source of energy for muscular work and all the nutritive processes.
  - Help to maintain the body temperature.
  - Protect the body tissues by forming reserve fund for time of need (glycogen).
  - Excess carbohydrates are converted into adipose tissue.
  - May be used in constructive processes.
- **Derangements of**
  1. Glycogenesis breaks down, giving rise to alimentary glycosuria.
  2. Glycogenolysis breaks down.
  3. Glycolysis breaks down.
  4. Normal impermeability of the kidneys breaks down.

Metabolism of Fats

- **Reconstruction**—In act of passing through epithelial cells of villi, glycerin and fatty acids combine to form fat.
- **Dependent upon**
  - Enzyme furnished by tissue cells or hormone from one of the ductless glands.
  - Oxidation of glucose.
- **Functions**
  - Serve as fuel, yield heat and other forms of energy.
  - Stored in tissues.
  - Synthesized to form more complex constituents of body.
- **Waste Products**
  - Carbon dioxide.
  - Water.
- **Derangements of**
  - Result in formation of compounds of an acid character—acidosis.
- **Obesity**
  - Due to excessive amounts of carbohydrates and fats.
  - Sedentary life and absence of worry are contributing factors.

Metabolism of Proteins

- Absorbed as amino-acids. From the intestines blood passes through liver, before it reaches the general circulation.
- Amino-acids deaminized and split into non-nitrogenous and nitrogenous portion.
- Non-nitrogenous oxidized to CO_2 and H_2O or converted into glycogen.
- Nitrogenous passes through series of reactions—final waste product urea.
- Deamination takes place in body generally, liver shares in process.
- **Blood**
  - Amino-acids taken up by cells and used (1) to build new tissue, (2) to replace oxidized tissue, and (3) to form enzymes, hormones and chalones.

Metabolism of Proteins

- **Classification**
  - Endogenous—includes building up of amino-acids to tissue proteins and final disintegration to creatinin and urea.
  - Exogenous includes reactions affecting uncombined amino-acids, formation of urea from nitrogenous portion and glucose from non-nitrogenous portion, also secondary production of glycogen.
- **Nucleoproteins**
  - Nucleoproteins—process of digestion, protein separated from nucleic acid reduced to amino-acids, history same as above.
  - Nucleic acid gives rise to purin bodies of which uric acid is end-product excreted in urine.
  - Endogenous uric acid from nucleoproteins of tissue cells.
- **Nutritive value**
  - **Adequate** proteins contain all the materials for maintenance and growth of tissue.
  - **Inadequate** proteins serve same purpose as carbohydrates and fats.
- **Nitrogen Equilibrium**
  - Condition when the amount of protein nitrogen taken into the body in food is equal to the amount eliminated in the excreta.
  - Plus balance in favor of food means growth of new tissue—favorable condition during growth and convalescence from wasting illness.
  - Minus balance—means body is burning its own proteins.
- **Specific Dynamic Reaction**
  - Proteins speed up metabolic processes.
  - Heavy meat diet increases metabolic rate as much as 90 per cent.
  - Carbohydrates and fats may increase 30 to 40 per cent.

Amount of Food Needed

- Food source of energy for tissue building or work.
- **Total Metabolism**
  - Basal metabolism—energy necessary to keep body alive.
  - Cost of digestion—energy expended in working over food.
  - Energy required for work.
- **Calorie**
  - Unit of measurement for heat production.
  - Large Calorie = quantity of heat necessary to raise one kilogram (2.2 lbs.) of water 1 degree Centigrade or one pound of water 4 degrees Fahrenheit.
- **Carbohydrates**—1 gm. = 4 Cal.
- **Fat**— 1 gm. = 9 Cal.
- **Protein**— 1 gm. = 4 Cal.
- **Factors to be considered**—Age—activity—size—shape—body composition—lactation—climate.
- Ordinarily estimated at 40 Calories for each kilogram of body weight = 2450 to 2800 Calories for 70 kilograms or 154 lbs.
- **Distribution**
  - Proteins—10 to 15 per cent.
  - Fats—75 grams essential, 200 grams is maximum digestive capacity.
  - Carbohydrates—depends upon form in which taken, also on amount of fat.

Accessory Articles of Food

- **Flavors and Condiments** — Have no nutritive value, but increase the secretion of gastric fluid.
- **Stimulants**
  - Tea and coffee—stimulating action due to caffein.
  - Cocoa — Contains carbohydrate, fat, and protein. Stimulating effects due to theobromin.
  - Meat Extracts — Contain secretagogues which stimulate the gastric glands to secretion.
- **Alcohol**
  - Oxidized rapidly, yields heat.
  - Waste Products — Carbon dioxide; Water.
  - Favors Obesity — Moderate drinking creates keen appetite, and thus favors overeating. Lessens need for oxidation of fat or carbohydrates, hence these are spared to accumulate.

Foods to Regulate Body Processes

- *Ash constituents*—derived from calcium, iron, phosphorus, sulphur, magnesium, potassium, sodium, iodin, and chlorin. Foods rich in these elements are milk, egg, whole grain, peas, beans, green vegetables, and fruits.
- *Vitamins*—necessary to prevent specific diseases and malnutrition. Amounts of each required not known. Diet which meets all nutritive requirements, and in which milk, vegetables, and some fresh food is included, is thought to meet vitamin requirement.
- *Water*—sufficient to make good amount lost from tissues and to serve purposes listed on page 362. Estimated that daily requirement is about eight glasses.

CHAPTER XX

WASTE PRODUCTS; EXCRETORY ORGANS; DESCRIPTION OF THE ORGANS CONSTITUTING THE URINARY SYSTEM; URINE

In the previous chapters we have seen that the blood is constantly supplied by means of the respiratory and digestive mechanisms with the chemical substances it requires to maintain the life, growth, and activity of the body. These substances, entering the current of the blood, are carried to all the cells and are constantly combining with the chemical substances of which these cells are composed. One of the results of these chemical combinations is the formation of waste products, which must be removed from the body, as many of them are toxic.

WASTE PRODUCTS

The wastes of cell metabolism may be listed as follows:—

1. Soluble Salts { Nitrogenous salts, *e.g.*, urea. / Inorganic salts, *e.g.*, sodium chlorid.
2. Liquid—Water.
3. Gas—Carbon dioxide.
4. Solids—Waste materials from food.

These wastes are classed as excreta and the process by which they are removed from the body as excretion or elimination.

EXCRETORY ORGANS

The organs that function as excretory organs and the products that they eliminate may be tabulated as follows:—

	Essential	Incidental
Lungs	Carbon dioxide	Water
Kidneys	Water and soluble salts, resulting from metabolism of proteins, neutralization of acids, etc.	Carbon dioxide
Alimentary canal	Solids, bile, etc.	Water, carbon dioxide and salts.
Skin[1]	Heat regulatory	Water, carbon dioxide, and salts.

[1] For discussion of the functions of the skin see chapter XXI.

In this chapter we devote ourselves to the consideration of the urinary system, which includes the following organs; two *kidneys*, which form the urine from materials taken from the blood; two *ureters*, ducts which convey the urine away from the

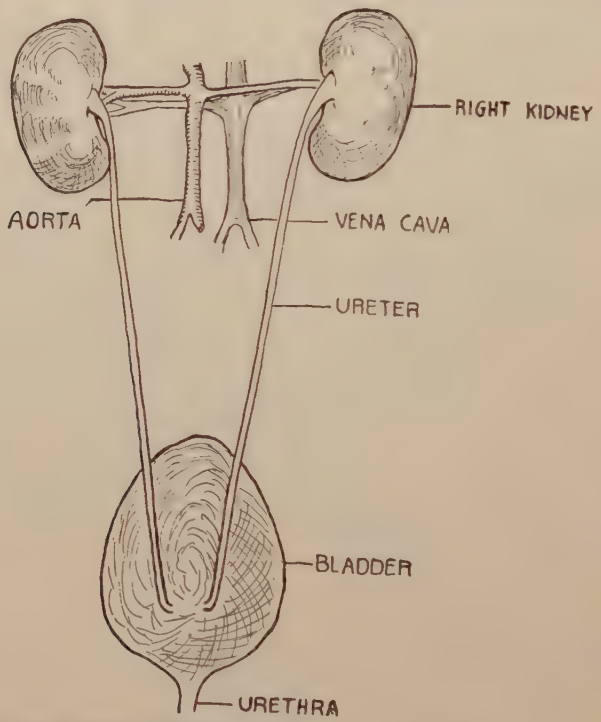


FIG. 207.—THE URINARY SYSTEM VIEWED FROM BEHIND.

kidneys; one *bladder*, a reservoir for the reception of urine; one *urethra*, a tube through which the urine passes from the bladder and is finally voided.

KIDNEYS

The kidneys are two compound tubular glands, placed at the back of the abdominal cavity, one on each side of the spinal column and behind the peritoneal cavity. They correspond in position to the space included between the upper border of the twelfth thoracic and the third lumbar vertebræ. The right is a little lower than the left in consequence of the large space occupied by the liver.

Capsule and supports.—The kidneys are covered by a thin but rather tough envelope of fibrous tissue called the capsule,

the inner surface of which is slightly attached to the substance of the kidney by means of fine fibers and blood-vessels. The kidneys are usually embedded in a mass of fatty tissue termed the adipose capsule, and are not held in place by any distinct ligaments, but rather by fatty tissue and the pressure and counter-pressure exerted upon them by neighboring organs.

They are bean shaped, with the concave side turned toward the spine, and the convex side directed outward. Near the

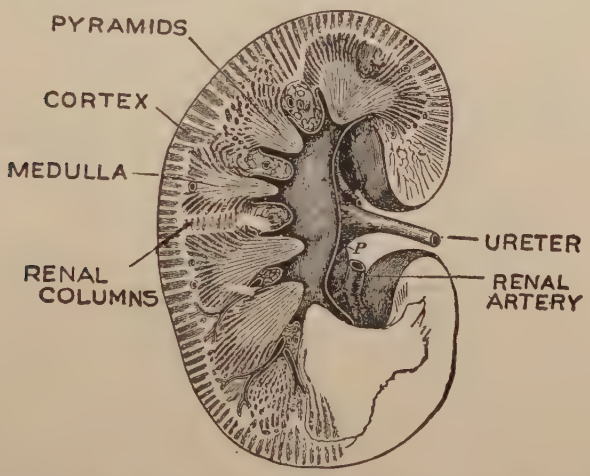


FIG. 208.—DIAGRAMMATIC LONGITUDINAL SECTION OF THE KIDNEY. *P*, Pelvis of the ureter. Each kidney is about four and one-half inches (11.25 cm.) long, two to three inches (5 to 7.5 cm.) broad, and one inch (2.5 cm.) thick, and weighs about four and one-half ounces (135 gm.). (Henle, from Huxley.)

center of the concave side is a fissure called the hilum, which serves as a passageway for the ureter, and for the blood-vessels, lymph-vessels, and nerves going to and from the kidney.

Anatomy of the kidney.—If a kidney is cut in two lengthwise, it is seen that the upper end of the ureter expands into a basin-like cavity, called the *pelvis* of the kidney. This pelvis is irregularly subdivided into smaller, cup-like cavities, called *calyces*, which receive the pointed projections of the kidney substance.

The substance of the kidney is readily seen by the naked eye to consist of two distinct parts: (1) an outer, and more solid portion, called the cortex (bark); and (2) an inner, striated portion, called the medulla (marrow), which is not a solid mass, but more or less distinctly divided into sections termed the *renal pyramids*. The cortical substance penetrates for a variable

distance between the pyramids, separating and supporting them. These inter-pyramidal extensions are called the renal columns (Bertini) and support the blood-vessels. The apices, or *papillæ*, of the pyramids are received by the cup-like cavities or calyces of the pelvis. The bulk of the kidney substance, both in the cortex and medulla, is composed of little tubes or tubules, closely packed together, having only just enough connective tissue to carry a large supply of blood-vessels and a certain number of lymphatics and nerves.

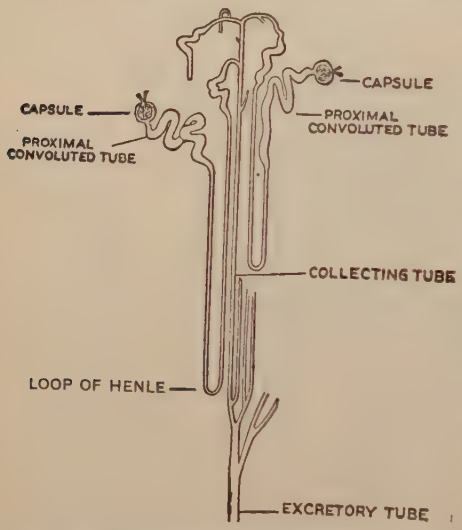


FIG. 209.—DIAGRAM OF THE COURSE OF TWO URINIFEROUS TUBULES.

Renal tubules.—Examined under the microscope, it is seen that the renal tubules begin as little hollow globes, called the *glomerular capsules* (capsules of Bowman) in the cortex of the kidney. These capsules are joined to the tubules by a constricted neck, and the tubules, after running a very irregular course, open into straight collecting tubes, which pour their contents through their openings in the pointed ends or papillæ of the pyramids, into the calyces of the kidney.

The tubules are composed of basement membrane, lined throughout by epithelial cells. The cells vary in the different parts of a tubule, those of the capsule and convoluted or irregular parts being more especially adapted to secretory purposes than the straight parts of the tubule.

Pyramid.—These collecting tubules *en masse*, together with interstitial tissue, blood-vessels, and lymphatics, make a pyramid. The number of pyramids varies.

Renal (or Malpighian) corpuscles.—In the cortical portion of the kidney are found renal corpuscles which consist of two parts: (1) a minute tuft of capillaries called a *glomerulus*, surrounded by (2) a closed capsule, called the *glomerular capsule*, which is the beginning of a renal tubule. The investment of the glomerulus by the

capsule is double and complete except at one point, where an afferent vessel enters and an efferent vessel leaves.

The blood-supply of the kidney.—For its size, the kidney is abundantly supplied with blood. The renal artery, coming directly from the aorta, divides, before it enters the hilus of the kidney, into several branches, which pass into the tissue of the

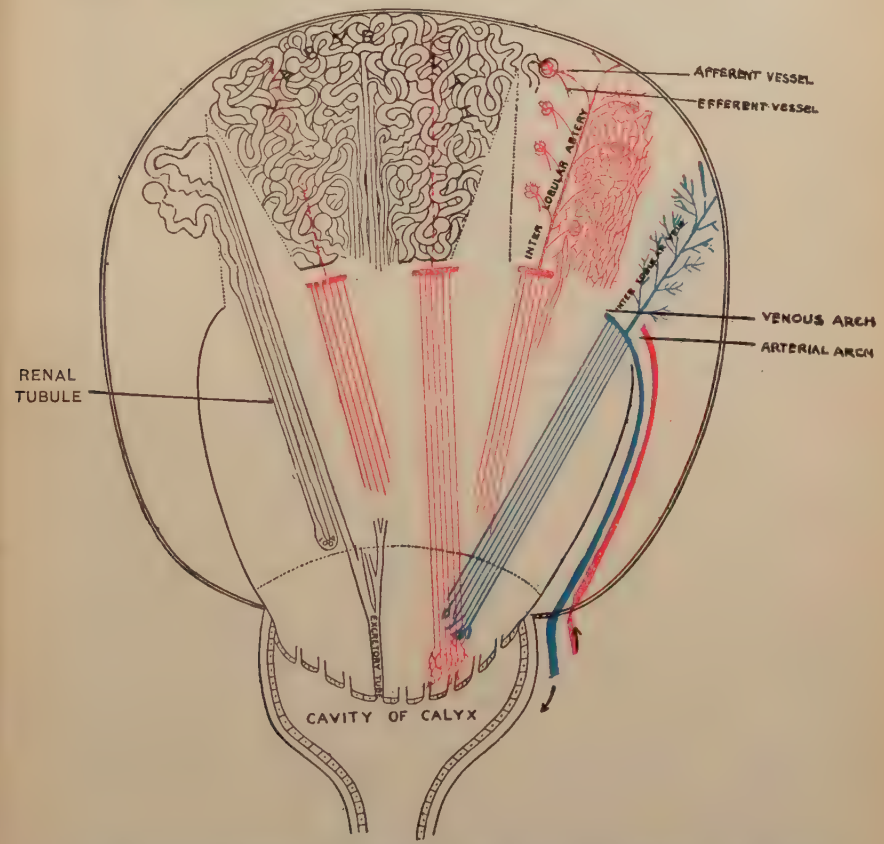


FIG. 210.—DIAGRAM OF A VERTICAL SECTION OF A LOBE OF THE KIDNEY SHOWING THE ARRANGEMENT OF TUBULES AND BLOOD-VESSELS IN THE LOBE. See Fig. 209 for an enlarged view of the tubule shown on the left, and Fig. 211 for an enlarged view of arrangement of blood-vessels shown on the right. The calyx embraces the apex of the medullary pyramid. It is lined with epithelium, which continues from it over the apex, the latter being perforated with the many apertures of excretory tubes. (Gerrish.)

organ. Branches from these arteries have two destinations: (1) into the cortex, and (2) into the pyramids.

(1) When the arteries reach the level of the base of the pyramid, the branches divide laterally to form more or less complete

arches between the cortex and medulla. From the arterial arches, vessels pass upward through the cortex (*interlobular*), giving off at intervals tiny arteries, each of which enters[2] the dilated commencement or capsule of a renal tubule. These tiny arteries, entering the capsule, are spoken of as afferent vessels. They push the thin walls of the capsule before them, break up into a knot of capillary vessels, called a *glomerulus*, and finally issue from the capsule as efferent vessels, near the point at which

FIG. 211.—PLAN OF THE BLOOD-VESSELS CONNECTED WITH THE TUBULES.

the afferent vessel entered. These efferent vessels are much smaller than the afferent vessels. They do not immediately join to form veins, but break up into a close meshwork or plexus of capillaries around the tubules, before they unite to form the larger vessels and pour their contents into the veins. These veins terminate in venous arches between the cortex and medulla.

(2) The pyramids also receive their blood-supply from the arterial arches. The blood passes downward in straight vessels between the renal tubules, to be returned by more or less straight veins to the venous arches, whence it is conveyed by large

[2] The artery does not penetrate the wall of the capsule, but the knot of capillary vessels is contained within the capsule, as the heart is contained within the pericardium.

branches into the renal vein, which leaves the kidney at the hilus and pours its contents into the inferior vena cava.

It is worthy of note that, unlike the lungs and the liver, the kidney receives blood from just one artery, and this blood distributed in different sets of vessels serves the purposes of nourishment for the kidney substance, and the purposes of excretion. It is from the capillaries of the glomeruli and the plexus of capillaries around the convoluted portion of the tubules, that the passage of waste material from the blood into the tubule takes place. Other capillaries serve to hold the blood that is used for nourishment.

Nerves.—The nerves of the kidney are derived from the renal plexus, a branch of the celiac plexus, and from the lesser and lower splanchnic nerves. The nerve fibers are disposed in plexuses in the walls of the blood-vessels. They are vasomotor nerves, and by regulating the contraction and dilatation of the blood-vessels, they influence the blood-pressure in the kidneys. It is thought the secretion of urine is regulated by the blood-pressure in the renal capillaries, and by direct stimulation of the kidney cells by chemical substances contained in the blood. These substances are the result of the general metabolism of the body, and it is possible that hormones may be produced that stimulate the kidneys and correlate their activities to conditions elsewhere in the body.

Function of the kidneys.—The function of the kidneys is to separate the constituents of urine from the blood, and thus help to maintain its normal composition. The kidneys extract almost all the protein waste, the greater part of the salts not needed by the blood, and about half of the excess water. The amount of water removed by the kidneys varies considerably and is chiefly dependent upon the activity of the sweat-glands. The kidneys also extract foreign substances, such as toxins, whether formed in the body, or taken into the body from outside. The concentration of urine, and not the quantity, is our criterion for judging the amount of work done by the kidneys. It is probable that they are most severely taxed when they have to remove from the blood a maximum of dissolved solids in a minimum of water.

The secretion of urine.—The exact way in which the kidneys separate the urine from the blood is not known, but several theories[3] have been proposed.

[3] For review of the various theories that have been proposed, consult physiologies listed in bibliography on page 526.

Into each hollow capsule which forms the beginning of a renal tubule an afferent vessel enters. This vessel breaks up into capillaries which form a bunch of looped and twisted blood-vessels called a *glomerulus*. The walls of the capsule being double, the glomerulus pushes back the inner wall or visceral layer, until the capsule is entirely filled, leaving only a small space between it and the outer wall or parietal layer. The blood in the glomerulus is only separated from the interior of the tubule by the thin walls of the capillaries and the inverted wall of the capsule. The vessel (afferent) which enters the capsule is larger than the issuing (efferent) vessel, and during its passage through the glomerulus, the blood is subjected to considerable pressure. As a result of this, a transudation of the watery constituents of the blood, with some dissolved salts, takes place through the walls of the blood-vessels and the walls of the capsule into the capsular space, then into the tubule. It is probable that in the loop of Henle there is a reabsorption of some of these dissolved substances (glucose, salts, etc.).

After leaving the capsule, the efferent vessel communicates with other similar vessels, which together form a meshwork or plexus of capillaries closely surrounding the tubules, so that the blood is again brought into close communication with the tubules. The tubules are lined with cells, and these cells appear to have the power of selecting from the blood some of the dissolved substances (especially the urea). The secretion of urine is a constant process. Blood-pressure in the renal vessels, and the velocity of the flow through these vessels, affects the secretion. Blood-pressure in the renal vessels is usually increased by (1) ingestion of water; (2) contraction of the blood-vessels in other parts of the body which drives more blood to the kidneys. This may be (*a*) contraction of the blood-vessels in the superficial parts of the body caused by chilling the surface and in other ways, or (*b*) contraction of the visceral blood-vessels under the influence of the sympathetic nervous system stimulated by various emotional states, nervousness, worry, fright, etc. (3) It is thought that the activity of the tubules is stimulated by the urea content of the blood, the soluble salts, glucose, etc. Foreign substances in the blood stimulate the renal cells to increased activity.

Diuretics is the name given to drugs (caffein, digitalis, etc.) which stimulate the activity of the renal cells, and *diuresis* is the term applied to the increased secretion of urine. When the increase is marked and long-continued, it is called *polyuria*.

The ureters.—The ureters are two tubes which connect the kidneys with the bladder and serve as a passageway to convey urine from the kidneys to the bladder. They consist of a distended portion called the *pelvis*, which is contained within the kidney, and a *duct*. Each duct is about the diameter of a goose-quill, and from ten to twelve inches (25 to 30 cm.) long. They possess three coats: an outer fibrous coat, a middle muscular consisting of an internal longitudinal, and an external circular layer; and an inner mucous lining which is continuous above with that of the pelvis of the kidney, and below with that of the bladder.

The contractions of the muscular coat produce peristaltic waves, which force the urine from the pelvis into the bladder.

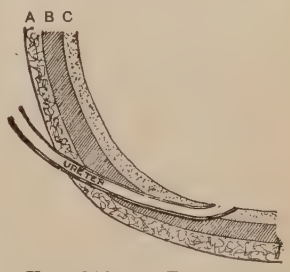


FIG. 212. — DIAGRAM SHOWING ENTRANCE OF URETER INTO BLADDER. *A*, fibrous coat; *B*, muscular coat; and *C*, mucous coat.

BLADDER

The bladder is a hollow muscular organ situated in the pelvic cavity behind the pubes, in front of the rectum in the male, and in front of the anterior wall of the vagina, and the neck of the uterus, in the female. It is a freely movable organ, but is held in position by folds of peritoneum and fascia. During infancy it is conical in shape and projects above the upper border of the pubes into the hypogastric region. In the adult, when quite empty, it is placed deeply in the pelvis; when slightly distended it has a round form; but when greatly distended, it is ovoid in shape and rises to a considerable height in the abdominal cavity. It is customary to speak of the widest part as the *fundus*. It has four coats:—(1) The **serous** coat is a reflection of the peritoneum, and only covers the upper portion of the fundus. (2) The **muscular** coat has three layers, an inner longitudinal, middle circular, and outer longitudinal. The circular fibers are collected into a layer of some thickness around the opening of the bladder into the urethra. These circular fibers form a sphincter muscle which is normally in a state of contraction, only relaxing at intervals, when the accumulation of urine within the bladder renders its expulsion necessary. (3) The **areolar** coat connects the mucous and muscular. (4) The **mucous** membrane lining the bladder is continuous with that of the ureters and the urethra. There are three

openings into the bladder, two at the upper part of the fundus—one on each side connecting with the ureters, and the third in the lower part connects with the urethra.

Function.—The bladder serves as a reservoir for the reception of urine. When moderately distended, it holds about one pint (about one-half liter).

The urethra.—The urethra is a narrow membranous canal which extends from the bladder to the external orifice which is named the meatus urinarius. Its normal diameter is about one-quarter of an inch (6.3 mm.) but it admits of considerable dilatation. Its length is about an inch and a half (3.8 cm.) in the female, and eight inches (20 cm.) in the male. In the female the urethra is placed behind the symphysis pubis, and is embedded in the anterior wall of the vagina. Its direction is obliquely downward and forward, its course being slightly curved, with the concavity directed forward and upward. Its external orifice is the narrowest part and is located between the clitoris and the opening of the vagina. (See Fig. 240.)

The wall of the urethra consists of three coats, an outer muscular coat, a submucous coat, and an inner mucous coat which is continuous with that of the bladder.

Micturition.—Urine is secreted continuously by the kidneys. It is carried to the bladder by the ureters, and at intervals is expelled from the bladder through the urethra. The act by which the urine is expelled is called micturition. Experiments indicate that the desire to urinate is due to sensory stimulation in the bladder itself caused by pressure of urine. The act is essentially a reflex through the central nervous system.

Involuntary micturition.—Involuntary micturition may occur as the result of lack of consciousness, and as the result of spinal injury involving the nerve centers which send nerves of control to the bladder. It may be due to a want of *tone* in the muscular walls, or it may result from some abnormal irritation due to irritant substances in the urine, or to disease of the bladder (cystitis). Excessive nervousness may provoke the desire to urinate when there is only a small amount of urine in the bladder. This desire may also be aroused by visual and auditory impressions such as the sight and sound of running water.

Retention of urine.—Retention or failure to void urine may be due to: (1) some obstruction in the urethra or in the neck of the bladder (2) nervous contraction of the urethra, and (3) dulling of the senses so that there is no desire to void. In the

last two conditions retention is often overcome by measures which induce reflexes, *i.e.*, pouring water over the vulva, or the sound of running water. If micturition does not occur, and the bladder is not catheterized, distention of the organ may become extreme, and there is likely to be constant leakage, or voluntary voiding of small amounts of urine without emptying the bladder. These conditions are described as retention with overflow.

Suppression of urine.—A far more serious condition than retention is the failure of the kidneys to secrete urine. This is spoken of as suppression or *anuria*. This may occur when the blood-vessels are much relaxed as in shock. Unless suppression is relieved a toxic condition known as uremia will develop. When the secretion of urine is decreased below the normal amount the condition is spoken of as *oliguria*.

THE URINE

Normal urine may be described as a transparent, yellowish liquid, with a characteristic odor and a specific gravity of about 1.020.

Transparency.—The transparency of urine is relative and may be replaced by a marked turbidity, or the formation of sediments. On a vegetable diet the transparency is lessened, due to a precipitation of phosphates. If allowed to stand normal urine develops a cloudy appearance due to the mucin secreted by the lining of the urinary tract. In disease the urine may become clouded by the presence of pus.

Color.—The color of urine depends upon the quantity voided and the relative amounts of water and coloring matter. If the quantity is abnormally increased, it is usually more dilute and of a paler color; as, for instance, the copious light-colored urine of hysteria or diabetes insipidus. One exception to this is diabetes mellitus, where the quantity is increased, but the color is dark because of the presence of sugar. When the quantity is diminished as in fevers, it is generally highly colored, because the amount of solids present is large. Other causes of change of color are the presence of foreign substances, such as sugar, bile, pus, much mucin, and large doses of certain drugs. In pernicious anemia, the erythrocytes are destroyed at an abnormally rapid rate, and pigment derived from these cells, will be absorbed by the blood circulating in the liver, and later extracted in the kidneys, resulting in a dark-colored urine.

Reaction.—The reaction is subject to wide variations depend-

ing upon the diet, but is usually on the acid side of neutral with an average pH of about 6. On a high protein diet the acidity is increased, on a vegetable diet it is decreased. If human urine is allowed to stand for any length of time, it will become alkaline, because bacteria will decompose the protein constituents (urea), into ammonia and other alkalies.

Specific gravity.—In health the specific gravity may vary from 1.010 to 1.030 depending on the relative proportion of solid matter and water. Specific gravity is the weight of the urine as compared with the weight of an equal volume of distilled water at 60° F. (15° C.) the weight of water being considered 1.000. When the solids are dissolved in a large amount of water, the specific gravity will naturally be lower than when the urine is more concentrated. In diabetes mellitus there is a copious flow of urine of high specific gravity due to the presence of large quantities of sugar. In nephritis the amount of urine is decreased below normal, and the specific gravity is low, because the kidneys are not eliminating all the excess salts and protein waste. Even though albumin is present in the urine it does not increase the density to the extent that its normal constituents do.

Quantity.—The average quantity of urine secreted in twenty-four hours by a healthy adult is about forty ounces (1.2 liters). A child voids relatively more urine than an adult, but absolutely it voids less.

From 2– 5 years, 16–24 ounces (480– 720 cc.).
From 5– 8 years, 24–32 ounces (720– 960 cc.).
From 9–16 years, 32–40 ounces (960–1200 cc.).

The quantity of urine may be increased by (1) the ingestion of a large amount of liquid, (2) checking of perspiration, (3) the action of diuretics, (4) nervousness, (5) certain diseases such as diabetes insipidus, diabetes mellitus, and hysteria.

The quantity of urine may be decreased by (1) the ingestion of a small amount of liquid, (2) excessive loss of fluid from the body as by hemorrhage, vomiting, diarrhea and high fever, (3) disease of the kidneys, and (4) the action of diaphoretics, muscular activity, or any treatment that induces free perspiration.

Composition of urine.—The composition of urine is very complex; even in health it varies, depending on the kind and quantity of food eaten, etc. It is not difficult to understand this complexity when one recalls that the kidneys eliminate some of all the end-products resulting from food metabolism, together with the products of bacterial fermentation in the stomach and

intestines. Under pathological conditions the composition may be still further modified. For table showing composition of urine consult summary on page 434.

Water.—Water is lost from the body through the kidneys, the lungs, the skin, and the alimentary canal; the first being the most important. The greater the amount lost through the skin, the less will be secreted by the kidneys and *vice versa*. Through these organs, but mainly through the kidneys, the blood is being continually depleted of water, and this loss must be made good by the ingestion of water. When water is swallowed in excess the superfluous amount is eliminated through the kidneys.

Urea.—Urea ($CO(NH_2)_2$) constitutes about one-half of the solid constituents of the urine, and represents the chief end-product resulting from the metabolism of the proteins of the food and tissues. The result of the oxidation of protein material exists in the blood until it reaches the liver. Under the action of the liver cells this material is converted into urea. About 0.028 per cent of urea is present normally in the blood and tissues. The kidneys constantly remove urea as it is formed, and by their activity keep the amount of urea in the blood at the low level given above. If, for any reason, the kidneys fail to eliminate urea, the accumulation in the blood and tissues leads to a condition of poisoning.

Normally an adult voids about one ounce (30 gms.) of urea in twenty-four hours, but the quantity is increased by a diet rich in proteins, strenuous exercise, hot baths, fever in its early stages, and some diseases. A small amount of protein food, excessive vomiting, free perspiration, and diseases that interfere with elimination will decrease the amount of urea voided.

Creatin and creatinin.—Creatin ($C_4H_9N_3O_2$) occurs in the blood in small amounts, but normally is not present in the urine of adult man. It is constantly present in the urine of children, in women it is said to occur after menstruation, during pregnancy and in the puerperium. Creatin is also present during fevers and starvation. By loss of water (H_2O) creatin becomes creatinin. Creatinin ($C_4H_7N_3O$) occurs in the urine constantly. Its physiological history is imperfectly known. Under normal conditions the amount of creatinin formed in the body is independent of proteins eaten. This has led some observers to think that it represents an end-product of the metabolism of living protein tissue, rather than one of the results of the metabolism of food protein. The difficulty in interpreting these facts satisfactorily has led to

two views. One view is that creatin and creatinin are related, and that creatin is one of the end-products of the breakdown of living tissue. It is produced constantly and is normally converted to creatinin before it is excreted in the urine. Under exceptional conditions such as starvation or fever, the amount produced is too large to be wholly changed to creatinin, with the result that both creatin and creatinin appear in the urine. A second view is that the metabolism and significance of creatin and creatinin are different, *i.e.*, that creatin is constantly formed in the tissues as the result of their metabolism, but it is not converted to creatinin. In fact it is not regarded solely as a waste product prepared for excretion, but as a product which can be utilized under certain conditions for the reconstruction of the protein molecule. If not utilized, then it may be excreted as creatin and creatinin.

Ammonia.—Ammonia (NH_3) is a constant constituent of urine averaging about .7 gms daily. It occurs mainly as ammonium chloride and ammonium urates. In metabolic disturbances where oxidation is incomplete the ammonia in the urine is increased. If the kidneys cannot produce ammonia rapidly enough to neutralize the acid there is a loss of alkali reserve and acidosis.

Hippuric Acid.—Hippuric acid ($C_9H_9NO_3$) is a constant constituent of human urine, averaging about 1 gm. daily. The quantity is increased on a vegetable diet and decreased on a flesh diet. However, hippuric acid in small amounts is present in the urine of starving animals and in those fed on meat. This is interpreted as an indication that it arises in part as a result of body metabolism.

Purin bodies.—Hypoxanthin, xanthin and uric acid are related chemically and appear to have a common physiological significance. They are derived from two sources: (1) The nucleoproteins of the tissues, described as endogenous, and (2) the nucleoproteins of the food described as exogenous. The endogenous portion, mainly uric acid, is found to be relatively constant and is thought to be chiefly a product of tissue metabolism. The exogenous portion varies, being dependent on the nucleoproteins eaten in food. The exogenous purin bodies represent the end-products of the metabolism of the nucleoproteins of food which involves the action of a number of different enzymes, and is a complicated process, the details of which are not agreed upon by different workers. A diet lacking nucleoproteins (purin-free diet) reduces the amount of exogenous purin bodies in the urine.

Salts.—The salts found in the blood are derived partly from

the food eaten, and partly from the metabolism of proteins, particularly the neutralization of acids. Sodium chlorid is the most abundant, and, next to urea, is the chief solid found in urine. In certain inflammatory conditions, coupled with serous exudate, *e.g.*, pneumonia, the amount of sodium chlorid excreted is very much diminished.

Abnormal constituents.—The chief abnormal constituents that are liable to appear in the urine are albumin, glucose, indican, acetone, casts, calculi, pus, and blood.

Albumin.—Serum-albumin is a normal constituent of the blood but usually the kidney cells do not allow it to pass into the tubules. Its presence in the urine is spoken of as albuminuria. Certain conditions favor albuminuria. These are: (1) increased blood-pressure in the renal vessels, (2) excessive amount of protein food in the diet, (3) nervous conditions, (4) irritation of the kidneys, and (5) abnormal conditions of the kidneys.

(1) Increased blood-pressure may be due to (*a*) stimulation of any part of the vasoconstrictor mechanism, (*b*) vigorous muscular exercise, (*c*) inelastic arteries due to arteriosclerosis, and (*d*) congestion of the kidneys because of interference with circulation through the renal vein. This interference may result from the pressure of tumors, or a pregnant uterus; or in diseases of the heart, liver and lungs.

(2) After a meal unusually rich in proteins, albumin may be excreted in the urine. This is known as alimentary albuminuria, and both this and temporary albuminuria due to increased blood-pressure resulting from normal causes, are known as functional albuminuria.

(3) Unstable nervous conditions such as exist (*a*) in children with neurotic tendencies, particularly during adolescence, and (*b*) in epileptics, favor the excretion of albumin.

(4) Irritation of the kidneys due to interference with circulation through the renal vein is likely to cause nephritis. In the treatment of poisoning by irritant drugs, and in infectious diseases, a liberal amount of water dilutes the irritating substances and lessens the danger of nephritis.

(5) In abnormal conditions of the kidneys associated with albumin in the urine, there is usually retention of the inorganic salts and protein waste. In consequence some of the salts may pass from the blood into the tissues, and by raising the osmotic pressure promote excessive transudation of fluid into the tissues, thereby causing edema or dropsy. Retained protein waste is

not poisonous, but it may undergo chemical changes which transform it into toxic substances and in this way cause the condition called uremia.

Glucose.—Normal urine contains so little sugar that for clinical purposes it may be considered absent. In health the amount of glucose present in the blood varies from 0.07 to 0.1 per cent. A higher per cent is irritating to the tissues, so when the quantity of sugar eaten is greater than the system can promptly change to glycogen and fat, the kidneys excrete it. When glucose is found in the urine from this cause, it is called *temporary glycosuria.* Temporary glycosuria frequently follows an injury to the head, or occurs during convalescence from fevers. In these cases it is thought to be due to temporary inability of the system to oxidize sugar.

Indican.—Indican[4] is a potassium salt that is formed from indol. Indol results from the putrefaction of protein food in the large intestine. It is absorbed by the blood and carried to the liver, which it is thought changes the indol to indican, a less poisonous substance. Traces of indican are found in normal urine, but the presence of it in any amount is abnormal and denotes: (1) excessive putrefaction of protein food in the intestines, or (2) putrefaction in the body itself as in abscess formation. Excessive putrefaction may be due to a diseased condition of the intestine that interferes with absorption, to a diet containing too much protein food, or to constipation. The presence of indican in the blood sometimes confers a distinctly fecal odor on the breath, for it is to this body that the odor of feces is due.

Acetone.—Acetone is a volatile substance that is thought to be the result of incomplete oxidation of fats in the cells. Fats are less readily oxidized than carbohydrates and for their oxidation, the oxidation of carbohydrates seems to be essential. If the sugar oxidation is defective, it follows that fat oxidation will be defective. Acetone is found in the urine of individuals suffering from defective metabolism, and in the urine of normal individuals during periods of fasting.

Casts.—In some abnormal conditions the kidney tubules become lined with substances which harden and form a mould or cast inside the tube. Later these casts are washed out by the urine, and their presence in urine can be detected by the aid of a microscope. They are named either from the substances composing them or from their appearance. Thus there are (1) pus

[4] See page 385.

casts, (2) blood casts, (3) epithelial casts from the walls of the tubes, (4) granular casts from cells which have decomposed and form masses of granules, (5) fatty casts from cells which have become fatty, and (6) hyaline casts which are formed from coagulable elements of the blood.

Calculi.—Deposits of solid matter that have been precipitated from the urine are called urinary calculi or stones. These vary in size, shape, and composition; the size and shape being determined largely by their composition and location. They may be formed in any part of the urinary tract from the tubules to the external orifice of the urethra. The causes which lead to their formation are (1) an increase in the slightly soluble constituents of the urine, (2) a decrease in the amount of water secreted, and (3) abnormally acid or abnormally alkaline urine.

Pus.—In suppurative conditions of any of the urinary organs pus cells are present in the urine.

Blood.—In cases of acute inflammation of any of the urinary organs, of tuberculosis, of cancer, and of renal stone, blood may be found in the urine. If present in large quantity, the urine is deep red, and this condition is known as hematuria.

Toxicity of urine.—As urine is the medium by which the body gets rid of toxic material, it follows that urine itself is toxic, and must be eliminated, else a condition of toxemia will result. During illness the kidneys always try to eliminate any poisonous substances that find their way into the blood, whether these substances result from defective metabolism or from bacterial activity. This accounts for the fact that after a severe illness the kidneys are often left in a damaged condition, and suggests a copious intake of water in order to lessen the concentration of toxic materials, and thereby lessen the chances of injury to the tissues.

SUMMARY

Wastes of Cell Metabolism	1. Soluble salts	Nitrogenous salts, *e.g.*, urea.
		Inorganic salts, *e.g.*, sodium chlorid.
	2. Liquid—water.	
	3. Gas—carbon dioxide.	
	4. Solids—waste materials from food.	
Excretory Organs	Lungs.	
	Kidneys.	
	Alimentary Canal.	
	Skin.	
Urinary System	**Kidneys** (2)—secrete urine.	
	Ureters (2)—ducts which convey urine from kidneys to bladder.	
	Bladder (1)—reservoir for urine.	
	Urethra (1)—tube through which urine is voided.	

KIDNEYS

Location
- Posterior part of lumbar region, behind peritoneum.
- Placed on either side of spinal column and extend from upper border of twelfth thoracic to third lumbar vertebra.

Capsule and supports
- Covered by tough envelope of fibrous tissue.
- Supported by fat and by pressure and counterpressure of neighboring organs.

Size and shape
- About four and one-half inches long, two to three inches broad, and one inch thick.
- Weight about four and one-half ounces (135 gms.).
- Bean-shaped, tubular glands.
- Concave side toward spine, convex side outward.
- Hilum—fissure near center of concave side serves for vessels to enter and leave.

Anatomy of the kidney
- **Pelvis**—upper expanded end of ureter.
- **Calyces**—cup-like cavities of the pelvis that receive papillæ of pyramids.
- **Cortex**—outer, more solid portion.
- **Medulla**—inner, striated portion.
- **Renal Columns**—interpyramidal extensions of cortical substance.

Renal tubules
- Begin as hollow globes or capsules (Bowman's) in the cortex of kidney, and after a very irregular course open into straight collecting tubes which pour their contents into calyces of pelvis.

Pyramids
- Cone-shaped masses in the medullary portion of the kidney. Vary in number.
- **Bases** directed toward cortex.
- **Papillæ**—apices of the pyramids, directed toward pelvis.
- Consist of renal tubules, blood-vessels, and lymphatics, held together by connective tissue.

Renal corpuscles
- Minute tufts of capillaries—glomeruli—in the cortical portion of kidneys which are surrounded by inverted capsule of renal tubule

Blood-supply
- **Renal artery**—direct from aorta.
- Enters hilus of kidney, divides into many branches.

Arterial arches
- Lateral branches at the level of the base of the pyramids.
- 1. Send branches to cortex (cortical).
- 2. Send branches to pyramids.

Venous arches
- Lateral branches at level of base of pyramids.
- Receive blood from cortex.
- Receive blood from pyramids.

- Veins empty into renal vein, leave kidney at hilus, and empty into inferior cava.
- **Note**—Blood from renal artery serves for purposes of nourishment of kidney and purposes of excretion.

Nerves
- Nerves derived from the renal plexus, and from the lesser and lower splanchnic nerves.
- Vasomotor, by regulating size of blood-vessels influence blood-pressure.

KIDNEYS

Function

Secretion of urine

1. Process of filtration. Water and dissolved substances are filtered from the blood during the circulation through the glomeruli.
2. Probable reabsorption of some of the dissolved substances in the loop of Henle.
3. Selective action of the cells lining the renal tubules. Urea and other dissolved substances are separated from the blood during the circulation through the plexus of capillaries which surrounds the tubules.

Amount varies

1. Ingestion of water.
2. Contraction of blood-vessels in superficial and visceral areas.
3. It is thought the urea content of blood as well as other dissolved substances stimulate the activity of the tubules.

Ureters

Excretory ducts. Connect kidneys with bladder and serve as passageway for urine.

Consist of expanded portion called pelvis and duct.

Duct is size of goose-quill. 10-12 in. long.

Three coats

1. Mucous—lining.
2. Muscular
   - Inner, longitudinal layer.
   - Outer, circular layer.
3. Fibrous—carries blood-vessels and nerves.

Bladder

Hollow muscular organ.

Situated in pelvic cavity behind the pubes
- in front of rectum in male.
- in front of anterior wall of vagina and neck of uterus in female.

Freely movable. Held in position by folds of peritoneum and fascia.

Size, shape, and position depend upon age, sex, and whether bladder is full or empty.

Fundus—widest part.

Four coats

1. Mucous—lining.
2. Areolar—connects mucous and muscular.
3. Muscular
   - Inner layer—longitudinal.
   - Middle layer—circular.
   - Outer layer—longitudinal.
4. Serous—partial covering derived from peritoneum.

Three openings

- One on each side of upper part of fundus, connects with ureters.
- One in lower part connects with urethra.

Function

- Serves as a reservoir for the reception of urine.
- When moderately distended, holds about one pint.

Urethra

Membranous canal, extends from the bladder to the meatus urinarius.

1½ in. long in female, 9 in. long in male. ¼ in. in diameter but admits of dilatation.

In female behind symphysis pubis, and embedded in the anterior wall of vagina.

Three coats

1. Mucous—lining.
2. Submucous—supports network of veins.
3. Muscular
   - Inner—longitudinal.
   - External—circular.

Meatus urinarius—external orifice located between clitoris and vagina.

- **Micturition**
  - Act of expelling urine from bladder.
  - Occurs as result of irritation due to accumulation of urine in bladder.
  - Reflex act—controlled by voluntary effort.
- **Retention**
  - Failure to void urine.
  - Due to
    1. Some obstruction in urethra or neck of bladder.
    2. Nervous contraction of urethra.
    3. Dulling of the senses.
  - May be accompanied by constant leakage, or voluntary voiding of small amounts.

Suppression or anuria—Failure of the kidneys to secrete urine.

Oliguria—Deficient secretion of urine.

- **Urine**
  - **Transparency**—is relative, depending on diet, etc.
  - **Color**—depends on concentration. Relative amounts of water and solids.
  - **Reaction**—usually acid side of neutral, average pH about 6. Subject to wide variations.
  - **Specific gravity**—average about 1.020. Depends on concentration.
  - **Quantity**
    - Average about 40 ounces.
    - Increased by
      - Ingestion of large amount of liquid.
      - Checking of perspiration.
      - Action of diuretics.
      - Nervousness.
      - Diseases
        - Diabetes insipidus.
        - Diabetes mellitus.
        - Hysteria.
    - Decreased by
      - Ingestion of small amount of liquid.
      - Excessive loss of fluid from the body as by hemorrhage.
      - Vomiting, diarrhea.
      - High fever.
      - Disease of kidneys.
      - Increased action of skin.

- **Composition of Urine**
  - Water, 95 per cent.
  - Soluble Salts 5 per cent
    - **Organic** about 3.7 per cent
      - **Urea** ($CO(NH_2)_2$) (2 per cent of total solids).
      - Creatin ($C_4H_9N_3O_2$) and Creatinin ($C_4H_7N_3O$).
      - Ammonia (NH_3).
      - Hippuric acid ($C_9H_9NO_3$).
      - Purin bodies
        - Hypoxanthin (monoxypurin) $C_5H_4N_4O$.
        - Xanthin (dioxypurin) $C_5H_4N_4O_2$.
        - Uric acid (trioxypurin) $C_5H_4N_4O_3$.
      - Other substances.
    - **Inorganic** about 1.3 per cent
      - Sodium chlorid.
      - Sulphates.
      - Phosphates.
      - Salts of
        - Potassium.
        - Ammonium.
        - Magnesium.
        - Calcium.
      - Iron.
      - Other substances.

Water
- Water lost from body through the kidneys, the lungs, the skin, and the alimentary canal.
- Mainly by kidneys, water content of blood is constantly depleted.
- Superfluous water ingested—eliminated by kidneys.

Urea
- End-product resulting from metabolism of proteins.
- About 0.028 per cent present normally in blood and tissues.
- Increased by:
  - Diet rich in proteins.
  - Strenuous exercise—hot baths.
  - Some diseases.
- Decreased by:
  - Small amount of protein food.
  - Excessive vomiting, free perspiration.
  - Diseases that interfere with elimination.

Creatin $C_4H_9N_3O_2$
- Occurs in blood in small amounts.
- Normally not present in urine of adult man.
- Constantly present in urine of children; in women after menstruation, during pregnancy and puerperium.
- Two Views:
  1. Creatin—end-product of breakdown of living tissue, produced constantly and converted to creatinin before excretion.
  2. Metabolism and significance of creatin and creatinin differ.

  Creatin constantly formed as result of metabolism of tissues, but can be used for reconstruction of protein molecule. If not used changed to creatinin and excreted.

Creatinin $C_4H_7N_3O$
- By loss of water creatin becomes creatinin. Is probably an end-product of the metabolism of protein tissue.

Ammonia NH_3
- Constant constituent of urine.
- Average amount 7 gms. daily.
- Amount increased in metabolic disturbances where oxidation is not complete.

Hippuric Acid
- Constant constituent of urine.
- Average about 1 gm. daily.
- Increased on a vegetable diet.
- Decreased on a flesh diet.

Purin Bodies
- Hypoxanthin ($C_5H_4N_4O$)
- Xanthin ($C_5H_4N_4O_2$)
- Uric acid ($C_5H_4N_4O_3$)

  End-products resulting from metabolism of nucleoproteins of food (exogenous) and tissues (endogenous).

  Purin-free diet reduces amount of exogenous purin bodies in the urine.

Salts
- Derived partly from food eaten, partly from metabolism of proteins, particularly neutralization of acids.
- Sodium chlorid is most abundant.

Abnormal constituents
- Albumin.
- Glucose.
- Indican.
- Acetone.
- Casts.
- Calculi.
- Pus.
- Blood.

Albuminuria
- Albumin in urine.
- 1. Increased blood-pressure in renal arteries due to
  - (*a*) stimulation of the vasoconstrictor mechanism.
  - (*b*) vigorous muscular exercise.
  - (*c*) arteriosclerosis.
  - (*d*) congestion of the kidneys, due to pressure or diseases of heart, liver and lungs.
- 2. Excessive amount of protein food.
- 3. Nervous conditions
  - Children of neurotic tendencies particularly during adolescence.
  - Epilepsy.
- 4. Irritation of kidneys—due to interference with venous return.
- 5. Abnormal conditions such as nephritis—retention of organic salts and urea may result in edema or uremia.

Glycosuria
- Normal urine contains little sugar.
- **Temporary Glycosuria**: Follows ingestion of large amount of sugar, injury to head, or during convalescence from fevers.
- **Diabetes Mellitus**: Glucose persists in urine even when carbohydrate food is not eaten.

Indican
- Indican is a potassium salt formed from indol.
- **Caused by**
  - Excessive putrefaction of proteins in intestines
    - due to interference with absorption.
    - due to excess of protein food.
    - due to constipation.
  - Putrefaction in body itself.

Acetone—Result of incomplete oxidation of fats.

Casts
- Substances which harden and form a mould inside of tubules
- Named from substances composing them or their appearance
- Varieties
  - Pus casts, blood casts.
  - Epithelial casts, granular casts.
  - Fatty casts, hyaline casts.

Calculi
- Deposits of solid matter precipitated from the urine, vary in shape and size.
- **Causes**
  - Increase in slightly soluble constituents of urine.
  - Decrease in amount of water secreted.
  - Abnormally acid or abnormally alkaline urine.

Pus—Due to suppurative conditions of urinary organs.

Hematuria
- Blood in urine.
- Inflammation of urinary organs, tuberculosis, cancer, renal stone.

CHAPTER XXI

THE SKIN; APPENDAGES OF THE SKIN. BODY HEAT; REGULATION OF HEAT. VARIATIONS IN TEMPERATURE

THE SKIN

Functions.—The functions of the skin are to serve (1) as a protective covering for the deeper tissues lying beneath it, (2) as an important organ in heat regulation, (3) as a sense organ, (4) as an excretory organ, and (5) as a respiratory organ. In man the interchange of gases through the skin is very slight, but in thin-skinned animals it is important. (6) To a limited extent the skin serves as an absorbing organ because it will absorb oily materials placed in contact with it. Infants are dosed with cod-liver oil by rubbing it into the skin. Some ointments are also absorbed, *e.g.*, mercury ointment.

Structure.—It consists of two distinct layers:—

(1) Epidermis, cuticle or scarf skin.

(2) Corium, cutis vera or derma.

Epidermis.—The epidermis is a stratified epithelium, composed of a number of layers of cells. It varies in thickness in different parts, being thickest on the palms of the hands and on the soles of the feet, where the skin is most exposed to friction, and thinnest on the ventral surface of the trunk, and the inner surfaces of the limbs. It forms a protective covering over every part of the true skin, upon which it is so closely moulded that the ridges of the true skin show through. Over most of the body these ridges are not very evident, but on the palms of the hands and the fingers and thumbs they are quite deep and form patterns (finger prints) peculiar to each individual, which practically never change regardless of the changes due to age, hard work, etc.

It consists of four layers from without inward, (1) the **stratum corneum,** (2) the **stratum lucidum,** (3) the **stratum granulosum,** and (4) the **stratum mucosum.**

The three upper strata consist of cells, which are practically dead, and are constantly being shed and renewed from the cells of the stratum mucosum.

The **stratum mucosum** consists of several layers of cells. The

cells of the deepest layer are columnar in shape and are sometimes called the stratum germinativum.

The growth of the epidermis takes place by the multiplication of these cells. As they multiply they push upward toward the surface those previously formed. In their upward progress they undergo a chemical transformation, and the soft protoplasmic cells become converted into the flat scales which are constantly being rubbed off the surface of the skin. The pigment in the skin of the negro, as well as that of the nipple in white races, is found in the cells of the stratum mucosum.

No blood-vessels pass into the epidermis; it, however, receives

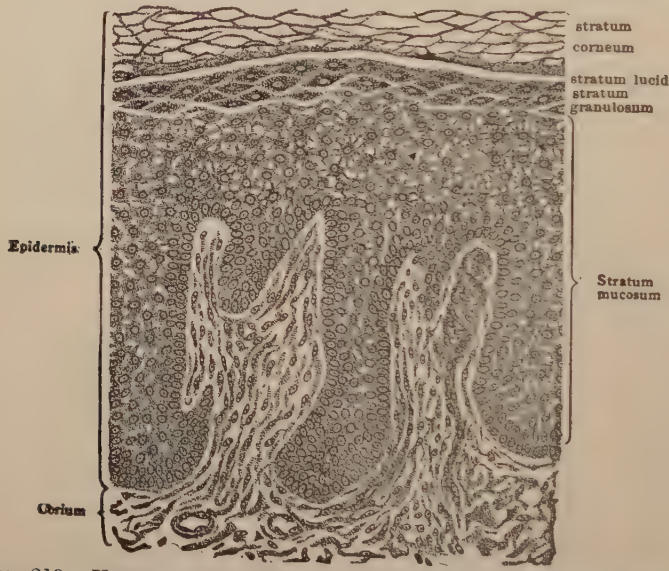


Fig. 213.—Vertical Section through the Skin of the Palmar Side of the Finger, Showing Two Papillæ (One of which Contains a Tactile Corpuscle) and the Deeper Layer of the Epidermis. (Schäfer.)

fine nerve fibrils between the cells of the germinative layer.

Corium.—The corium is a highly sensitive and vascular layer of connective tissue. It supports numerous blood-vessels, lymph-vessels, nerves, glands, hair follicles, and papillæ, and is described as consisting of two layers:—

(1) Superficial, or papillary layer.
(2) Deeper, or reticular layer.

(1) The surface of the **superficial** or **papillary** layer is increased by protrusions in the form of small conical elevations, called papil-

læ, whence this layer derives its name. They project up into the epidermis, which is moulded over them, and contain looped blood-vessels. Some papillæ, especially those in the palms of the hands, fingers, and tongue contain the terminations of nerve fibers in the shape of little bodies called *tactile corpuscles*.

The papillæ seem to exist chiefly for the purpose of giving the skin its sense of touch, being always well developed where the sense of touch is exquisite.

(2) The **deeper** or **reticular** layer of the corium is a continuation of the papillary layer, there being no real division between them. It is made up of bundles of white fibrous and some yellow elastic tissue.

The derma is attached to the parts beneath it by a layer of areolar tissue, here named *subcutaneous*, which layer contains a varying amount of fat, except that in the eyelids, labia minora, and scrotum.[1] The connection in some parts is loose and movable as on the front of the neck; in others, close and firm, as on the palmar surface of the hand and the sole of the foot. In youth the skin is both extensile and elastic, so that it can be stretched and wrinkled and return to its normal condition of smoothness. As age advances the elasticity is lessened, and the wrinkles tend to become permanent.

Blood-vessels.—The blood-vessels of the skin are found in the corium only. They form a network of capillaries in which the vessels are very close to each other, and send branches to the papillæ, the hair follicles, and the sudoriferous glands. The capillaries of the skin are so numerous that when distended they are capable of holding a large proportion of the blood contained in the body. The amount of blood they contain is dependent on their caliber, and this is regulated largely by the vasomotor nerves.

Nerves.—The skin is provided with a great variety of nerves.[2] They are classified as follows:—

(1) Motor nerves, including the vasoconstrictors and vasodilators distributed to the blood-vessels, and motor nerves distributed to the arrector muscles (arrectores pilorum.)

(2) Nerves concerned in the temperature sense, which terminate in the hot and cold spots of the skin.

(3) The nerves concerned in the sense of touch and pressure.

(4) Nerves which are stimulated by pain.

(5) Secretory nerves, which are distributed to the glands.

Because of the number of afferent nerves which lead from the

[1] External organs of generation. [2] See page 459.

skin to centers in the brain and spinal cord, nearly every nerve center in the body may be affected by sensations arising in the skin. It is for this reason that hydrotherapeutic applications, heat, cold and counter-irritants excite so many and such varied reflexes.

THE APPENDAGES OF THE SKIN

The appendages of the skin are the nails, the hairs, the sebaceous gland, and the sudoriferous or sweat-glands.

The nails.—The nails are composed of clear, horny cells of the epidermis, joined so as to form a solid, continuous plate upon the ends of the fingers and toes. Each nail is convex on its outer surface, concave on its inner side, and closely adherent to the underlying corium, which is modified to form what is called the bed, or *matrix*, of the nail. At the hinder part of the bed of the nail the skin forms a deep fold, in which is lodged the root of the nail.

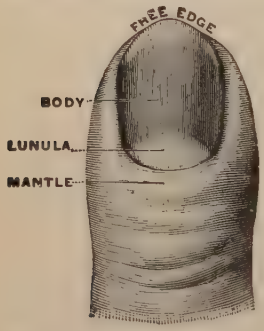


Fig. 214.—Thumb-nail. (Gerrish.)

The nails grow in length by multiplication of the soft cells in the stratum mucosum at the root. These cells are transformed into dry, hard scales, which unite into a solid plate, and the nail, constantly receiving additions from below, slides forward over its bed and projects beyond the end of the finger. When a nail is thrown off by suppuration or torn off by violence, a new one will grow in its place provided any of the cells of the stratum mucosum are left.

The hairs (pili).—The hairs are a growth of the epidermis, developed in little pits, the hair follicles, which extend downward into the deeper part of the true skin, or even into the subcutaneous tissue. The hair grows from the bottom of the little pit or follicle. The part which lies within the follicle is known as the root, and that portion which projects beyond the surface of the skin is called the shaft. The substance of the hair is composed of coalesced cells, arranged in different layers, and we usually distinguish three parts in the shaft of a hair:—

(1) *Cuticle*—an outer layer of delicate, scale-like cells, which overlap each other.

(2) *Cortex.*—a middle portion which constitutes the chief part of the shaft. It is formed of elongated cells. These cells and the

intercellular spaces contain a varying amount of pigment, and the color of the hair depends upon the quantity. Gray hair is usually due to loss of pigment; but it may be due to the formation of air bubbles or vacuoles in the medulla or fibrous layer. These make the hair appear white because of the way they reflect the light.

(3) *Medulla*—an inner layer or central pith formed of round cells. The short fine hairs on the surface of the body do not have this layer, and sometimes it is absent from long coarse hairs.

The root of the hair is enlarged at the bottom of the follicle into a bulb. This bulb is composed of soft growing cells, and fits over a vascular papilla which projects into the bottom of the follicle. Hair has no blood-vessels but receives nourishment from the blood-vessels of the papilla.

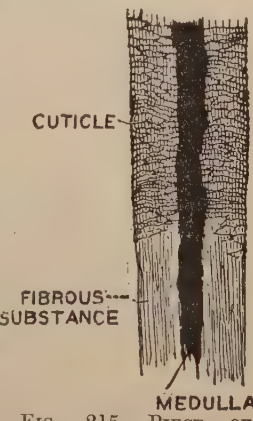


FIG. 215.—PIECE OF HUMAN HAIR. (Highly magnified.)

Growth of hair.—Hair grows from the bottom of the follicle by multiplication of the soft cells (matrix cells) which cover the papilla. These cells become elongated to form the fibers of the fibrous portion, and as they are pushed to the surface, they become flattened and form the cuticle. If the scalp is thick, pliable, and moves freely over the skull it is favorable to the growth of hair. A thin scalp that is drawn tightly over the skull tends to constrict the blood-vessels, lessen the supply of blood, and cause atrophy of the roots of the hair by pressure. In such cases massage of the head loosens the scalp, improves the circulation of the blood, and usually stimulates the growth of hair. The hairs are constantly falling out and constantly being replaced. In youth and early adult life not only may the discarded hairs be replaced, but there may be an actual increase of new hairs due to the development of new follicles containing matrix cells. When, from any cause, the matrix cells lose their vitality, new hairs will not develop.

With the exceptions of the palms of the hands, the soles of the feet, and the last phalanges of the fingers and toes, the whole skin is studded with hairs. The hair of the scalp is long and coarse, but most of the hair is very fine and extends only a little beyond the hair follicle.

Arrector (Arrectores pilorum) muscles.—The follicles contain-

ing the hairs are narrow pits which slant obliquely upward, so that the hairs they contain lie slanting on the surface of the body. Connected with each follicle are small bundles of involuntary muscle fibers called the arrector muscles. These muscles pass from the surface of the true skin, *on the side to which the hair slopes*, obliquely downward, to be attached to the bottom of the follicle. When these muscles contract, as they will under the influence of cold or terror, the little hairs are pulled up straight, and stand "on end"; the follicle also is dragged upward, and in this way the roughened condition of the skin known as "goose-flesh" is produced. The contraction of these muscles also forces the secretion of the sebaceous glands to the surface, and forces the blood from the superficial capillaries to the interior.

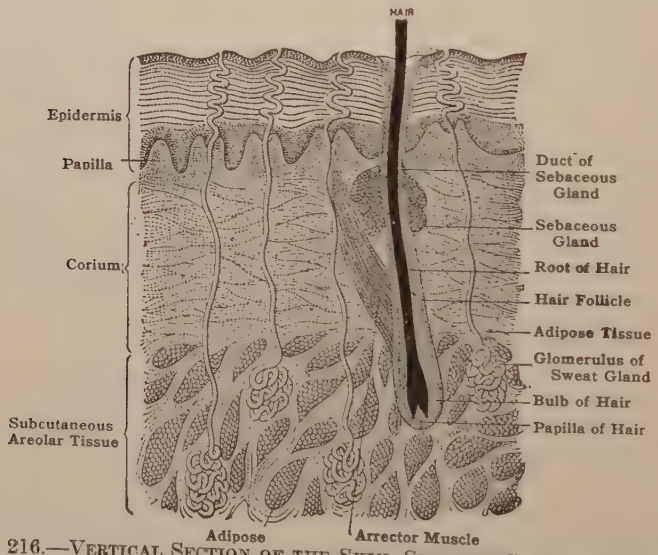


FIG. 216.—VERTICAL SECTION OF THE SKIN, SHOWING SEBACEOUS GLANDS, SWEAT-GLANDS, HAIR AND FOLLICLE, ALSO ARRECTOR MUSCLE. (Gerrish.)

Sebaceous glands.—The sebaceous glands are small, saccular glands, which lie between the hairs and their arrector muscles. They occur everywhere over the skin surface, with the exception of the palms of the hands and the soles of the feet. They are especially numerous around the apertures of the nose, mouth, external ears and anus. Each gland consists of a single duct which emerges from a sacculated enlargement. This enlargement is overspread with a network of capillaries. From the gland a small duct ascends, and opens either upon the surface of the skin,

or as is more common, into a hair follicle. In the latter case the secretion from the gland passes out to the skin along the hair. Their size is not regulated by the length of the hair. Thus, some of the largest are found on the nostrils and other parts of the face, where they may become enlarged with pent-up secretion. This retained secretion often becomes discolored, giving rise to the condition commonly known as blackheads. It also provides a medium for the growth of pus-producing bacteria and consequently is a common source of pimples and boils.

Sebum.—The secretion of the sebaceous glands is called sebum. It contains fats, soaps, cholesterin, albuminous material, remnants of epithelial cells, and inorganic salts. It serves to remove waste matters and is classed as an excretion, but its more important purposes are to keep the skin and hair soft and pliable, to form a protective layer on the surface of the skin, and to prevent the too rapid loss of heat from the body. An accumulation of this sebaceous matter upon the skin of the fetus furnishes the thick, cheesy, oily substance called the *vernix caseosa*. The secretion of sebum is continuous, and seems to be augmented by an increased supply of blood in the skin.

Sudoriferous or sweat-glands.—The sweat-glands are simple, convoluted, tubular glands with the blind ends coiled into little balls which are lodged in the true skin or subcutaneous tissue; from the ball the tube is continued as the excretory duct of the gland up through the corium and epidermis, and finally opens on the surface by a slightly widened orifice called a pore. Each tube is lined by a secreting epithelium continuous with the epidermis. The coiled end is closely invested by a meshwork of capillaries, and the blood in the capillaries is only separated from the cavity of the glandular tube by the thin membranes which form their respective walls. The secretory apparatus in the skin is somewhat similar to that which obtains in

FIG. 217.—COILED END OF A SWEAT-GLAND. *a*, the coiled end; *b*, the duct; *c*, network of capillaries, inside which the sweat-gland lies.

the kidneys; in the latter the blood-vessels are coiled up within the tube, while in the skin the tube is coiled up within the mesh-work of blood-vessels. See Fig. 217.

The sweat-glands are abundant over the whole skin, but they are largest and most numerous in the axillæ, the palms of the hands, soles of the feet, and the forehead.

Perspiration, or sweat.—The sweat is a watery, colorless liquid, slightly turbid, of a salty taste, with a distinctive odor which varies in different parts of the body. The reaction is usually acid although in profuse sweating it becomes alkaline or neutral, pH is 5.1 to 7.5. It is an excretion, the chief normal constituents of which are about 2 per cent of organic substances to 98 per cent water. The organic substances consist of salts, fatty acids, a small quantity of carbon dioxide, and a slight amount of urea. In various forms of kidney disease urea may be present in considerable quantity, the skin supplementing to a certain extent the deficient work of the kidneys.

Quantity of perspiration or sweat.—Under ordinary circumstances, the perspiration that we are continually throwing off evaporates from the surface of the body without our becoming sensible of it, and is called *insensible perspiration*. When more sweat is poured upon the surface of the body than can be removed at once by evaporation, it appears on the skin in the form of drops, and we then speak of it as *sensible perspiration*.

The amount secreted during twenty-four hours depends upon the general condition of the body and the surroundings. It is estimated to average about one quart (.95 liter), but it may be increased to such an extent that even more may be secreted in an hour. It is *increased* by: (1) increased temperature or humidity of the atmosphere; (2) a dilute condition of the blood; (3) exercise; (4) pain; (5) nausea; (6) mental excitement or nervousness; (7) dyspnea; (8) use of diaphoretics, *e.g.*, pilocarpin, Calabar bean, strychnin, nicotin, camphor, etc.; and (9) certain diseases, such as tuberculosis, acute rheumatism, and malaria.

The secretion of sweat is *decreased* by: (1) colds, (2) voiding of a large quantity of urine, (3) diarrhea, (4) certain drugs such as atropin and morphin in large doses, and (5) certain diseases, such as fevers, diabetes, and some cases of paralysis.

Activity of the sweat-glands.—The sweat-glands are richly supplied with secretory nerve fibers. The activity of these glands may be influenced by external heat, dyspnea, muscular exercise, strong emotions, and the action of various drugs. In all such

cases the effect is supposed to be the result either of direct stimulation of the nerve-endings in the glands, or indirect stimulation through the sensory nerves of the skin. The common cause of profuse sweating is a high external temperature or muscular exercise. It is known that the high temperature acts upon the sensory cutaneous nerves and stimulates the sweat fibers indirectly.

Functions of the sweat-glands.—While sweat is an excretion, its value lies not so much in the elimination of waste matter as in the loss of body heat by the evaporation of water. Each gram of water requires about 0.5 Calorie to cause it to evaporate, and this heat is taken from the body. This loss of heat helps to balance the production of heat that is constantly taking place. When the kidneys are not functioning properly, and the blood contains an excessive amount of waste matter, the sweat-glands will excrete some of the latter, particularly if their activity is stimulated. In the condition known as uremia[3] when the kidneys secrete little or no urine, the percentage of urea in the sweat rises.

Ceruminous glands.—The skin lining the external auditory canal contains modified sweat-glands called ceruminous glands. They secrete a yellow, pasty substance resembling wax which is called cerumen.

BODY HEAT

From the standpoint of heat production animals may be divided into two great classes:—

(1) **Constant temperature**[4] animals, or those whose temperature remains practically constant whether the surrounding air is hotter or cooler than the body. Birds and mammals (including human beings) are in this class.

(2) **Variable temperature**[5] animals, or those whose temperature varies with that of the surrounding medium, *e.g.*, snakes, frogs, fishes, etc. In winter their temperature is low, and in summer their temperature approximates that of their surroundings, hence they are only cold-blooded in cold weather. The human fetus is in this class.[6]

The great difference between these two classes is in their reac-

[3] See page 430. [4] Homoiothermous. [5] Poikilothermous.

[6] At birth the heart-regulating mechanism is not "in working order," and infants are not able to regulate their body temperature, hence the importance of keeping them warm. Premature infants are even less able to regulate their body temperature, hence need of special means to keep them warm.

tions to external temperature. A cold environment reduces the temperature of the cold-blooded creature, reduces the metabolism of all its tissues, and thus reduces its heat production. The warm-blooded animal reacts in precisely the opposite way. Since his temperature remains constant, his heat production must increase in order to neutralize the effect of cold surroundings.

Production of heat.—Heat in the body is produced by such chemical changes going on in the tissues as are associated with oxidation. The contraction of every muscle, all secretory activity, and probably all nervous reactions, give rise to small amounts of heat, and these form the total quantity of heat produced in the body. All of these chemical changes consist essentially of a union of oxygen with carbon and hydrogen to form carbon dioxide and water. The carbon and hydrogen are derived from food. Consequently the heat of the body is derived from food by a process of oxidation which reduces complex substances to simple ones, releasing energy in the form of heat, motion, secretory activity, etc. Since all the tissues of our body take part in the processes of oxidation, every cell may be described as a producer of heat. But tissues differ in their activities and in the quantity of heat they produce. The most important heat-generating organs are the skeletal muscles which are always in a state of tone and constitute about 50 per cent of the body weight. Next to these are the glands. We might liken the different tissues of the body to so many fireplaces stored with fuel, the fuel in some of the fireplaces being more easily ignited and burning more rapidly than in others. Minor sources of heat are friction, *i.e.*, that caused by the movements of the muscles, and the circulation of the blood; hot substances ingested; and radiation from the sun and heating appliances.

Distribution of heat.—The blood permeates all the tissues in a system of tubes or blood-vessels, and serves as an absorbing medium for the heat. Wherever oxidation takes place and heat is generated, the temperature of the blood circulating in these tissues is raised. Wherever, on the other hand, the blood-vessels are exposed to conditions which are cool because of heat lost by evaporation, etc., as in the moist membranes in the lungs, or the more or less moist skin, the temperature of the blood is lowered. But these changes are not effected instantaneously and consequently the temperature of some internal parts must always be higher than that of others. This is particularly true of the liver because its metabolism is never at a standstill, and its blood-

vessels are well protected against loss of heat. Because of this the temperature of the blood in different parts of the body varies slightly, but the circulation now through warmer and again through cooler parts, tends to keep the average temperature at 100° F. (37.8° C.).

Loss of heat.—Heat is continually being produced in the body, and continually leaving the body by the skin and the lungs, and by the urine and feces which are at the temperature of the body when voided. It has been calculated that in every 100 parts, about:—

1792 calories or 73.0 per cent is lost by conduction and radiation from the skin.
364 calories or 14.5 per cent is lost by evaporation.
182 calories or 7.2 per cent, vaporization of water, } 10.7 per cent is lost by
94 calories or 3.5 per cent, warming of air, } expired air.
48 calories or 1.8 per cent is lost by urine and feces.

From these figures it is evident that the skin is the important factor in getting rid of body heat. This is due: (1) to the large surface offered for radiation, conduction, and evaporation; (2) to the large amount of blood which it contains.

The temperature and humidity of the atmosphere may cause considerable difference in the percentages given above. A low temperature will increase the loss of heat by radiation and decrease that by evaporation. A high temperature will decrease the loss of heat by radiation and increase that by evaporation, owing to the greater production of sweat. Heat is lost by the evaporation of sweat, by the warming of air taken into the lungs (approximately 10 qts. per minute) and by the evaporation of the water which leaves the body by the lungs. It requires 0.5 Calorie to cause the evaporation of one gram of water, or about 500 Calories for the evaporation of one quart (.95 liter) of water. It is estimated that under ordinary circumstances it requires about 500 Calories daily to cause the evaporation of the sweat, and about 250 Calories to cause the evaporation of the water (about one pint) lost through the lungs. In hot weather the perspiration may be greatly increased, and more heat than usual is lost in this way, particularly if the humidity is not excessive. High humidity interferes with the evaporation of sweat, because air can only take up a certain amount of moisture. For this reason heat is more acutely felt when the humidity is high, even though the temperature is low, than when the humidity is low and the temperature high. Heat prostration and sunstroke are more likely to

occur on hot days when the humidity is high than when it is low. A breeze favors evaporation, because it tends to drive away evaporated moisture, hence the comfort derived from an electric fan which keeps the air in motion.

THE REGULATION OF BODY HEAT

The temperature of the body is due to the maintenance of a certain balance between heat production,[7] and heat dissipation. The part which the nervous system plays in this relationship is still an open question. The fact that infants cannot perform this function until some time after birth indicates that heat regulation follows a course parallel to the development of the nervous system. To many physiologists it has seemed reasonable to suppose that this balance was controlled by a definite set of heat nerves connected with a heat-regulating center in the brain. There is no convincing evidence of the existence of a definite set of heat nerves, but much experimental evidence indicates the existence of a heat-regulating center in the brain. A conservative view is that the balance between heat production and heat loss is controlled by the activities of the structures listed below, and these activities may be coördinated by a special heat-regulating center in the brain.

Heat Production	1. The quantity and character of food. 2. The motor nerve centers, and the motor nerve fibers to the skeletal muscles.
Heat Loss	1. The respiratory center. 2. The sweat centers and sweat nerves. 3. The vasomotor center and vasomotor nerves. 4. The water-content of the blood.

Heat production. —(1) In a previous chapter we described how the oxidation of different food-stuffs produces varying amounts of heat, and how the digestion products of food-stuffs, particularly proteins stimulate the metabolism of the body and cause an increased amount of heat to be produced. In this connection the action of enzymes and some of the internal secretions, *e.g.*, thyroxin is important. Thyroxin increases the oxidations of the body and stimulates all of the metabolic processes. During digestion heat is produced partly by the peristaltic action of the intestines and partly by the activity of the various digestive glands, particularly the liver. Cold weather stimulates the

[7] Heat production is designated as thermogenesis, heat dissipation as thermolysis, and the relationship between the two as thermotaxis.

appetite, and an increased amount of food, usually accompanied by an increase of fats increases heat production.

(2) The motor nerve-fibers which are distributed to the skeletal muscles are indirectly stimulated by cold. It causes the muscles to contract and speeds up the processes of oxidation. Muscular contractions give rise to heat, therefore muscular activity is used as a means to counteract the effects of external cold. On the other hand, muscular activity does not increase the temperature in hot weather to any marked extent. This is accounted for by the fact that when muscular exertion causes the blood to circulate more quickly than usual, the blood-vessels in the skin dilate, the sweat-glands at the same time are excited to pour out more abundant secretion, and the heated blood passing in larger quantities through the cutaneous vessels, which are kept well cooled by the evaporation of the perspiration, the general average temperature of the body is maintained.

Heat Loss.—(1) The stimulation of the sensory nerves of the skin that are affected by cold influences the respiratory center, increases the rate of the respirations, and consequently increases the loss of heat. In man respiration plays only a small part in heat regulation, but in animals that do not perspire, respiration is an important means of regulating the temperature.

(2) When the external temperature is high, the nerve-endings which respond to heat are stimulated, and these impulses are transmitted over sensory nerves to the nerve centers controlling the motor nerves of the sweat-glands. The motor nerves stimulate the activity of the sweat-glands, and an increased amount of sweat is poured out upon the surface of the body. An increased amount of heat is required to vaporize this sweat, and thus heat is lost. Excessive humidity interferes with the evaporation of water, and thus interferes with the loss of heat; hence the discomfort experienced on hot, humid days.

(3) The sensory nerves which are stimulated by heat not only transmit impulses that stimulate the sweat-glands to activity, but at the same transmit impulses that result in the depression of the vasoconstrictor nerves of the arterioles of the skin. In consequence the arterioles dilate and more blood is sent to the surface to be cooled. When the external temperature is low, the sensory nerve-endings which are stimulated by cold transmit impulses which result in stimulation of the vasoconstrictors, and consequent contraction of the arterioles of the skin. This lessens

the amount of blood in the skin arterioles, and lessens the amount of heat loss.

(4) Recently it has been suggested that the concentration of the blood is a factor to be considered. The water of the body holds heat, and when the external temperature is low, water is withdrawn from the blood to the tissues, and the blood is more concentrated. When the external temperature is high water is withdrawn from the tissues to the blood. When the blood is dilute an increased amount of water is brought to the surface and an increased loss of heat results, but when the water is withheld in the interior of the body less heat is lost. Other factors to be considered are (1) size, (2) age, and (3) constitution.

Size.—The quantity of heat produced by well-nourished animals, including man, is relatively constant, but the larger the surface of the body exposed to a cooler medium, the greater must be the loss of heat, since the heat lost is related to the *area of surface*. Small animals present a proportionately larger surface for their weight to the surrounding medium than larger animals, hence the loss per unit of weight is greater, and this must be compensated for by a greater heat production.

Age.—In children the heat production is relatively large, because they are active and growing. Moreover, young children have not the constancy of temperature which is an evolved characteristic of adult life. On the contrary, they are subject to changes of body temperature which would be of grave import in an adult.

Constitution.—Individuals differ greatly in their power of heat loss. Apart from differences in size, and in the faculty of perspiration, there exist differences in compactness of shape, and in the amount of adipose tissue protecting the viscera.

Clothing.—By clothing we can aid the functions of the skin and the maintenance of heat; though, of course, clothes are not in themselves sources of heat. The kind of clothing to be worn should be determined by the necessity for diminishing the loss of heat as in cold weather, or facilitating this loss as in warm weather. Clothing of any kind captures a layer of warm and moist air between it and the skin, and thus dimishes greatly the loss by evaporation and radiation. In considering the heat value of clothing the important properties are: (1) whether it is loosely or tightly woven, (2) its thickness, and (3) its color.

(1) Materials that are loosely woven will be warmer than those that are tightly woven, because the meshes in a loosely woven

material are capable of holding air, which is a poor conductor of heat, and thus prevents radiation. It is also true that two layers of thinner material are usually warmer than one layer of thicker material, because a layer of air is captured between the two.

(2) Thick material does not allow the warm air next the body to penetrate to the outside.

(3) Dark-colored materials absorb heat to some extent, hence they are warmer than light-colored textiles.

Thick, porous materials are used to keep the body warm. Wool has an additional advantage, as evaporation takes place more slowly from it than from linen, cotton, or silk, and it has a greater capacity for absorbing moisture, so that the layer of air next to the skin does not become saturated with moisture. Thin and very porous materials help to keep the body cool, because they allow the air to penetrate to the skin, and thus assist the evaporation of sweat.

Hot baths.—The primary effect of a hot bath is to prevent radiation of heat from the surface of the body, and some increase in temperature may result. If the bath is not continued for too long a time, this effect is counteracted by the increased perspiration that follows.

Cold or tonic baths.—The primary effect of a cold bath is similar to the effect of cold air. The cold contracts the arterioles of the skin, drives the blood to the interior, and increases oxidation. If the bath is a short one and is followed by friction (contrast condition, cold followed by heat), the reaction is for the arterioles to dilate, the heated blood is sent to the surface, the circulation is quickened, and there is a consequent loss of heat. In health the gain in heat is usually balanced by the loss of heat and the purpose of a cold bath is to exercise the arterioles and stimulate the circulation. If the bath is continued for some time, the temperature of the skin, and of the muscles lying beneath, is reduced, and either the heat-producing processes may be checked and a loss of temperature result; or shivering may intervene. In this case the muscular contractions and constriction of the blood-vessels stimulate metabolism and heat production. When cold baths are given for the purpose of increasing heat elimination, friction is used during the bath to prevent shivering. Friction stimulates the sensory nerves of the skin, causes dilatation of the arterioles, and favors the flow of hot blood to the surface, thus decreasing the sensation of cold and increasing heat elimination.

If properly given, cold baths stimulate the nervous system, improve the tone of the muscles, including the muscles of the heart and blood-vessels, stimulate the circulation, and favor the elimination of heat.

VARIATIONS IN TEMPERATURE

Normal variations.—The temperature of the human body is usually measured by thermometers placed in the mouth, axilla, or rectum.[8] Such measurements show slight variations, as the temperature in the interior of the body is slightly higher than on the surface of the skin. The average temperature in the rectum[9] is 98.9° F. (37.2° C.), in the axilla is 98° F. (36.6° C.), in the mouth is 98.3° F. (36.8° C.).

Other normal variations depend upon such factors as time of day, exercise, meals, age, sex, season, climate, and clothing. The lowest temperature is usually in the early morning about six, it rises slowly during the day, reaches its maximum in the evening about six and falls again during the night. This corresponds to the usual temperature ranges in fever, when the minimum is in the early morning, and the maximum is in the evening. Muscular activity and food may cause a slight increase in temperature. These seem to be the factors that cause the increase in temperature during the day. In the case of night workers who sleep during the day, the increase in temperature occurs during the night which is the period when food is eaten and work performed. Age has some influence. Infants and young children have a slightly higher temperature than adults. Their heat-regulating mechanism is more easily disturbed and rise of temperature is caused by slight disturbances of digestion or metabolism and usually is less significant than the same increase in adults. Aged people show a tendency to revert to infantile conditions, and their temperature is usually slightly higher than in middle life. It is said that women have a slightly higher rate of metabolism than men. The effect of climate and clothing has been discussed.

Abnormal variations. Fever.—The term fever is applied to an abnormal condition characterized by increased temperature, increased rate of heart action, increased respiration, increased tissue waste, faulty secretion, and various other symptoms such

[8] This indicates the balance between heat production and heat loss but gives no indication of the quantity of heat produced.

[9] Rectal temperature is the most reliable; and that by mouth (if properly taken) is almost equally reliable. Axillary temperature has little value.

as thirst, weakness, and apathy. Some of the symptoms accompanying fever may be due to the substances or conditions causing the fever, and some to the high temperature, and some to both.

Cause.—The exact cause of fever is unknown. It may be due to increased heat production, diminished heat loss, or both. Fever is usually accompanied by (1) increased catabolism of body tissue, as shown in the increased urea content of the urine, even though the dietary protein is not increased. In explanation of this it is suggested that the toxins which cause the fever produce some change in the cells which makes them susceptible to the action of oxidizing enzymes, so that oxidation and heat production are abnormally increased. (2) Usually the superficial blood-vessels are contracted and this is thought to be caused by the toxins acting on the vasoconstrictor centers. It is believed that fever and the conditions that accompany it are protective reactions to overcome the effect of toxins on the body. The reasons for this are based on various laboratory experiments. Small animals have been inoculated with bacteria or bacterial toxins, and then kept for a time at a temperature of about 105° F. (40° C.), with the result that they resisted the infection better than animals who were not subjected to this higher temperature. In connection with this bacteriologists remind us that many bacteria are killed at a temperature slightly above that of the body, and it may be that a high body temperature favors the formation of immune bodies. The contraction of the superficial blood-vessels sends more blood to the interior of the body, thus providing an increased number of phagocytes and antibodies to fight the infection.

Subnormal temperature.—In some maladies the temperature falls distinctly below normal. This is due chiefly to diminished metabolism. In cases of starvation the fall of temperature is very marked, especially during the last days of life. The diminished activity of the tissues first affects the central nervous system; the patient becomes languid and drowsy, and finally unconscious; the heart beats more and more feebly, the breath comes more and more slowly, and the sleep of unconsciousness passes insensibly into the sleep of death.

SUMMARY

Skin

- **Functions**
  1. Protective covering for deeper tissues.
  2. Important organ in heat regulation.
  3. As a sense organ.
  4. As an excretory organ.
  5. As a respiratory organ
     - Small amount oxygen taken in.
     - Small amount carbon dioxide is thrown off.
  6. To a limited extent as an absorbing organ.
- **Consists of**
  - **Epidermis is a stratified epithelium**
    1. Stratum corneum — Practically dead cells being constantly shed and renewed from the stratum mucosum.
    2. Stratum lucidum
    3. Stratum granulosum
    4. Stratum mucosum — Soft protoplasmic cells that are constantly multiplying by cell division.
  - **Corium is a layer of connective tissue**
    1. Papillary layer—papillæ are minute conical elevations of the corium. They contain looped blood-vessels and some contain terminations of nerve fibers called tactile corpuscles.
    2. Reticular layer — Bundles of fibrous and elastic tissue, with network of blood-vessels, lymphatics, and nerves.
- **Blood-vessels**—They are found in corium only. Send branches to papillæ and glands of skin. Capable of holding a large proportion of total amount of blood in body.
- **Nerves**
  1. Motor, to blood-vessels and arrector muscles.
  2. Nerves concerned in temperature sense.
  3. Nerves concerned in sense of touch and pressure.
  4. Nerves stimulated by pain.
  5. Secretory nerves which are distributed to the glands.
- **Appendages**
  - Nails.
  - Hairs.
  - Sebaceous glands.
  - Sudoriferous or sweat-glands.

Nails

- Consist of clear, horny cells of epidermis.
- Corium forms a bed or matrix for nail.
- Root of nail is lodged in a deep fold of the skin.
- Nails grow from soft cells in stratum mucosum at root.

Hairs (pili)

- The hairs grow from the roots.
- The roots are bulbs of soft, growing cells contained in the hair follicles.
- Hair follicles are little pits developed in the corium.
- Stems of hair extend beyond the surface of the skin, consist of three layers of cells: (1) cuticle, (2) cortex, and (3) medulla.
- Found all over body, except
  - Palms of the hands.
  - Soles of the feet.
  - Last phalanges of the fingers and toes.
- Arrector muscles are attached to corium and to each hair follicle. Contraction pulls hairs up straight, drags follicle upward, forces secretion of sebaceous glands to surface, and forces blood to interior.

Sebaceous Glands

- Saccular glands, the ducts of which usually open into a hair follicle, but may discharge separately on the surface of the skin.
- Lie between arrector muscles and hairs.
- Found over entire skin surface except
  - Palms of hands.
  - Soles of feet.
- Secrete *sebum*, a fatty, oily substance, which keeps the hair glossy, the skin flexible, forms a protective layer on surface of skin, and prevents the too rapid loss of heat from the body.

Sweat-glands

- Tubular glands, consist of blind ends coiled in balls, lodged in subcutaneous tissue, and surrounded by a capillary plexus.
- Secrete sweat and discharge it by means of ducts which open exteriorly. (Pores).

Sweat

- Watery, colorless, turbid liquid, salty taste, distinctive odor, and usually an acid reaction, pH 5.1 to 7.5.
- Consists of 2 parts of organic substances, *i.e.*, salts, fatty acids, carbon dioxide, and urea, to 98 parts water.
- Average quantity, about one quart in twenty-four hours.
- Amount increased by
  1. Increased temperature or humidity of the atmosphere.
  2. Dilute condition of blood.
  3. Exercise.
  4. Pain.
  5. Nausea.
  6. Mental excitement or nervousness.
  7. Dyspnea.
  8. Use of diaphoretics, *e.g.*, pilocarpin, Calabar bean, strychnin, nicotin, camphor.
  9. Various diseases, such as tuberculosis, acute rheumatism, and malaria.
- Amount decreased by
  1. Cold.
  2. Voiding a large quantity of urine.
  3. Diarrhea.
  4. Certain drugs, *e.g.*, atropin and morphin in large quantities.
  5. Certain diseases
     - Fevers.
     - Diabetes.
     - Some paralyses.

Activity of Sweat-glands due to

1. Direct stimulation of nerve-ending in sweat-glands.
2. Indirect stimulation through sensory nerves of the skin.
3. Influenced by external heat, dyspnea, muscular exercise strong emotions, and the action of various drugs.

Function

- Importance *not* in elimination of waste substances in perspiration, but because of *heat* needed to cause evaporation of perspiration.
- When kidneys are not functioning properly, sweat-glands will excrete waste substances, particularly if stimulated.

Ceruminous Glands

- Modified sweat-glands.
- Found in skin of external auditory canal.
- Secrete cerumen, a yellow, pasty substance, like wax.

Body Heat

- Animals divided into 2 classes
  1. Homoiothermous or those which have an almost constant temperature. Birds and mammals (including human beings) are in this class.
  2. Poikilothermous or those whose temperature varies with that of their environment, *e.g.*, snakes, frogs and fishes. The human fetus is in this class.
- **Produced by**
  1. Chemical changes taking place in all the cells of the body.
     Consisting essentially of a union of oxygen with hydrogen and carbon derived from food.
  2. Minor sources
     - Friction of muscles, blood, etc.
     - Hot substances ingested.
     - Radiation from sun and heating appliances.
- **Distributed**—by the blood circulating through the blood-vessels.
- **Lost by**
  - Skin 2156 calories or 87.5 per cent
    - Offers large surface for radiation, conduction, and evaporation of sweat.
    - Contains large amount of blood.
  - Lungs—276 calories or 10.7 per cent is lost warming the expired air and the evaporation of the water of respiration.
  - Urine and feces—48 calories or 1.8 per cent is lost warming the urine and feces.

Regulation of body heat

- Due to maintenance of *balance* between heat production and heat dissipation.
- **Heat Production**
  1. The quantity and character of food.
  2. The motor nerve centers and the motor fibers to the skeletal muscles.
- **Heat Loss**
  1. The respiratory center.
  2. The sweat center and sweat nerves.
  3. The vasomotor center and nerves.
  4. The water content of the blood.
- Coördinated by heat-regulatory cells in the brain.
- **Other factors**
  1. Size.
  2. Age.
  3. Constitution.
- **Aided by**
  - (*a*) Use of suitable clothing.
  - (*b*) Use of hot and cold baths.

Variations in Temperature

- **Normal**
  1. Depends on where temperature is taken
     - Mouth.
     - Axilla.
     - Rectum.
  2. Depends on time of day
     - Lowest in early morning, about 6 A.M.
     - Highest in early evening, about 6 P.M.
  3. Slightly increased by muscular activity and the digestive processes.
  4. Age. Higher and more variable in
     - Infants, children, and the aged.
  5. Sex.
  6. Season.
  7. Climate.
  8. Clothing.
- **Abnormal**
  - **Fever**
    - **Symptoms**
      - Increased temperature.
      - Increased pulse.
      - Increased respiration.
      - Increased tissue waste.
      - Faulty secretion.
      - Various other symptoms such as thirst, weakness and apathy.
    - **Cause**—not definitely known.
    - **Value**—thought to be a protective reaction.
  - **Subnormal**—due to diminished metabolism.

CHAPTER XXII

SENSORY UNIT.—SENSATIONS: TASTE, SMELL, HEARING, AND SIGHT

The sensory nerves which we have discussed in Chapter VII have their peripheral endings in receptors or sensory end-organs. These receptors receive stimuli, transform these stimuli to nerve impulses and pass them on to the nerves which carry them to centers in the central nervous system for interpretation or for linkage with motor nerves.

Sensory unit.—A typical sensory unit consists of (1) a peripheral end-organ or receptor which in most cases is constructed so as to be responsive only to a special form of stimulus, (2) connecting neurons whose only function is to conduct the nerve impulses originating in the end-organ, and (3) a center in the nervous system which interprets and determines the quality of the sensation. In this connection physiologists use the phrase *specific nerve energy*[1] to designate the fact that each sense organ arouses its own specific quality of sensation, and no other. For example, the specific energy of the optic apparatus is visual sensation, and of the auditory apparatus is sound sensation. The view generally adopted is that this specificity is not due to the end-organs or conducting nerves, but to the center in the brain. It is through the agency of the sense organs that we derive information about ourselves, one another, and the world in which we live. The limitations of the sense organs restrict our knowledge of the many transformations of energy that are going on around us, except as we are able to devise means of extending them artificially. Thus our knowledge of the microscopic forms of life depends upon the extension of our sight by means of magnifying lens. Wireless waves circulated through the ether unknown to us until our sense of hearing was extended by the use of sound magnifying devices.

Sensation.—Sensation is the conscious result of the stimulation of receptors. The sensitiveness of the numerous receptors to stimulation varies; some respond to a very mild stimulus, *e.g.*, in

[1] The name specific energy does not refer to the quality of the nerve impulse carried.

some parts of the body the slightest pressure will arouse a sensation while a similar degree of pressure in another part may fail to produce any sensation at all. The minimal stimulus necessary to arouse a sensation in any receptor is described as the *threshold* stimulus for that organ.

Sensations are felt and interpreted in the brain. Our habit of projecting sensations to the part that is stimulated tends to obscure this fact. In reality we see and hear with our brains, because the eye and ear serve only as end-organs to receive the stimulus which must be carried to the brain and interpreted before we do see or hear.

Classification.—The senses have been classified into two groups, *i.e.*, special and common. The special senses are sight hearing, touch, taste and smell. All others are grouped as common. Another classification is dependent on the part of the body to which the sensation is projected, and the two groups are named external and internal. The external are hearing, sight, smell, temperature, etc., and the internal are hunger, thirst, muscle-sense, etc. A more recent classification is based on the location of the stimulus, *i.e.*, extero-ceptors receiving stimuli external to the body, proprio-ceptors receiving stimuli within the body, and intero-ceptors receiving stimuli from the alimentary tract. Still another classification is based upon the kind of stimuli, *i.e.*, chemo-receptors, taste, smell, etc.; mechanico-receptors, sound, touch, etc.; and radio-receptors, light, heat, cold, etc.

Cutaneous sensation.—The sensory nerves of the skin mediate four different qualities of sensation, *i.e.*, pressure, cold, heat, and pain. The surface of the skin is a mosaic of tiny sensory spots separated by relatively wide intervals. Each spot coincides with the location of some special end-organ and serves a specific sense. These various spots are placed either singly or in clusters. In some locations one variety predominates, in others another. It is a matter of common knowledge that the sensitiveness of these varieties of cutaneous sensation differs in different parts of the body, *e.g.*, the tip of the finger is more sensitive to pressure or contact than to alterations of temperature. The hot and cold spots and the pressure points can be located by passing a metallic point slowly over the skin. At certain points a feeling of contact or pressure will be experienced, and at other points a feeling of cold or heat, depending on whether the temperature of the instrument is higher or lower than that of the skin.

Classification of cutaneous sensations.—Some authorities sug-

gest that the cutaneous senses be classified on the basis of the loss of sensation after division of the cutaneous nerves and the subsequent, gradual, and separate return of these sensations, after suture of the divided ends. It has been found that the skin is supplied with two sets of nerve fibers which regenerate at different times and these are named respectively protopathic and epicritic. The *protopathic* group comprises three qualities of sensation, *i.e.*, (1) pain, (2) heat above 98° F. (37° C.), and (3) cold below 78.8° F. (26° C.). This system conveys sensations of

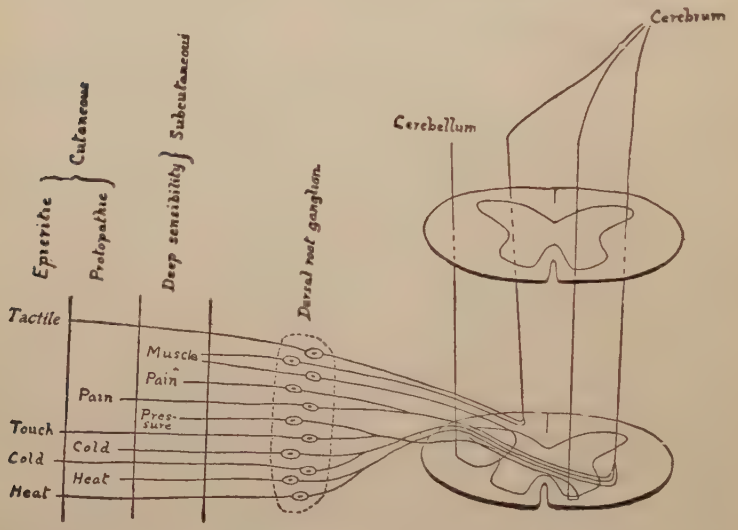


FIG. 218.—DIAGRAM OF COURSE OF CUTANEOUS FIBERS ON REACHING THE CORD. (Dawson.)

pain and of extreme changes of temperature but the sensibility is low and the localization poor. It is found in the viscera and from a functional standpoint may be considered as a defensive agency toward pathologic changes. The *epicritic* group contains separate fibers for heat, cold, light pressures, and tactile discriminations which give us sensations of (1) light touch and (2) small differences of temperature between 78.8° F. (26° C.) and 98.6° F. (37° C.), *i.e.*, the range of temperature to which the temperature nerves of the protopathic system are insensitive. This group constitutes the special characteristic of the skin area and is not found in other organs.

In addition to the protopathic fibers the deeper tissues are supplied with fibers which give us a sense of pressure, and in the

case of the muscles and joints, with fibers which give us a knowledge of the position of the movable parts of the body. The paths which these various fibers take in their journey through the central nervous system may be studied in Fig. 218.

Pain.—Excessive stimulation of any of the sense organs may give rise to unpleasant sensations, but it is thought that actual pain is caused by the stimulation of pain receptors. They are most abundant in the skin. Injury to the skin therefore causes intense pain. Handling and cutting of the viscera, however, do not produce acute pain. Over-distention of any of the hollow organs, or inflammatory conditions will cause pain. If other receptors are stimulated simultaneously with those of pain, the sensation is modified, usually augmented, *e.g.*, a burn causes stimulation of the hot spots and the pain receptors, hence the resulting pain is interpreted as burning. Pain acts as a danger signal by means of which abnormal processes may be detected. In many cases it compels rest and thereby favors the healing of a diseased part.

Referred pains.—Normally we are able to localize pain arising in the skin, accurately. On the contrary, pain arising in the internal organs is often located very inaccurately. For example, the pain from a severe toothache may be projected quite diffusely to the side of the face. An interesting fact in this connection is that such pains are often referred to points on the skin and may be accompanied by skin areas of tenderness. Pains of this kind are spoken of as referred pains. It has been shown that the different visceral organs have a more or less definite relation to certain areas of the skin. Pains arising from stimuli acting upon the intestines are located in the skin of the back, loins, and abdomen, in the area supplied by the ninth, tenth, and eleventh dorsal spinal nerves. Pains from irritations in the stomach are located in the skin over the ensiform cartilage, those from the heart in the scapular region. The explanation of this misreference is that the pain is referred to the skin region that is supplied from the spinal segment from which the organ in question receives its sensory fibers, the misreference being due to a diffusion in the nerve centers. (See Fig. 219, page 462.)

Muscle sense.—There are special sensory end-organs in the muscles, the so-called muscle spindles, and in the attached tendons the tendon spindles or tendon organs of Golgi. From these end-organs afferent fibers carry impulses to centers in the brain, which send out impulses along efferent fibers to the mus-

cles. There is thus a circle of nerves between the brain and the muscles, one nerve giving the sense of the condition of the muscle to the brain, and another carrying the impulse from the brain to the muscle. This gives us a certain consciousness of the condition of our muscles at all times, and enables us to coördinate the contractions of harmonious groups in order to produce voluntary movements.

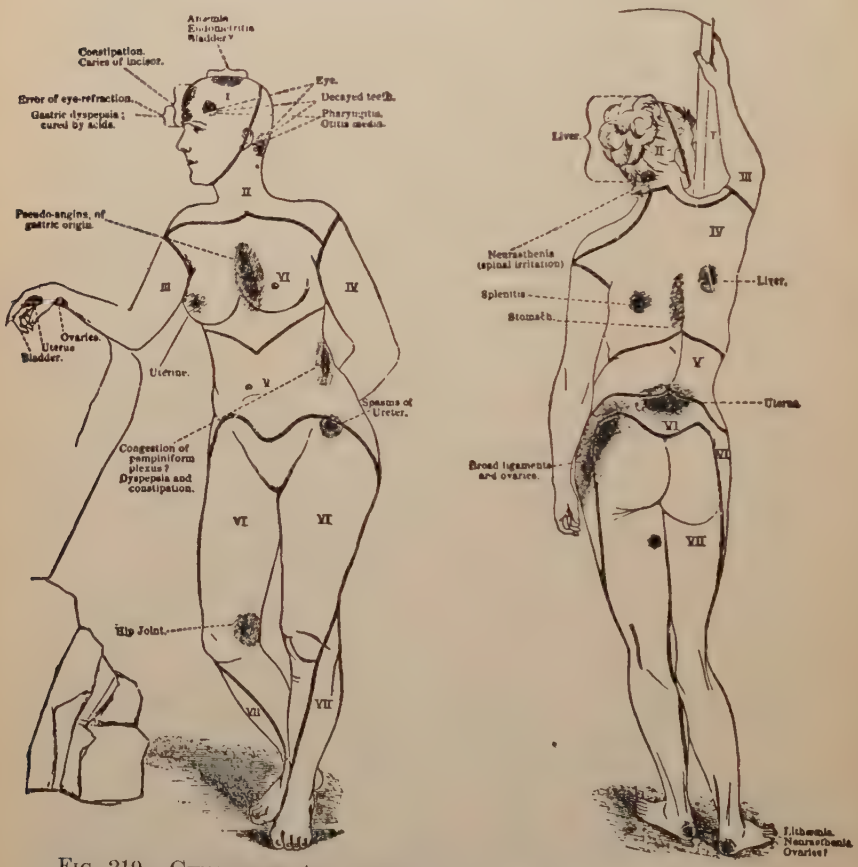


FIG. 219.—CUTANEOUS AREAS WHICH ARE THE SEAT OF REFERRED PAIN. (From Kellogg's "Rational Hydrotherapy," Modern Medicine Publishing Co., Publishers.)

Hunger.—The feeling that we commonly designate as hunger occurs normally at a certain time after meals and is usually projected to the region of the stomach. It is presumably due to contractions of the empty stomach, which stimulate the nerves distributed to the mucous membrane. If food is not taken, it

increases in intensity for a time and is likely to cause fatigue and headache. Professional fasters state that after a few days the pangs of hunger diminish and sometimes disappear. In illness hunger contractions may not occur at all, even when the food taken is not sufficient. Probably this results from a lack of muscular tone in the stomach. On the other hand, hunger contractions may be frequent and severe even if an abundance of food is taken regularly as in diabetes. This indicates malnutrition.

Appetite.—Some authorities class appetite as a mild form of hunger. Others consider that hunger and appetite constitute two different sensations mediated by two different physiological mechanisms. The sensory apparatus for hunger lies in the walls of the stomach, probably in the muscular coats, and is stimulated by the contractions of the musculature. The sensations aroused are more or less disagreeable. Appetite on the contrary is an entirely pleasant sensation aroused in part through the sensory nerves of taste and smell, and associated with previous experiences.

Thirst.—This sensation is projected to the pharynx, and the facts that are known seem to indicate that the sensory nerves of this region have the important function of mediating this sense. Our normal thirst sensations are designated as pharyngeal thirst to indicate the probable origin of the sensory stimuli. Local drying in this region, from dry or salty food, or dry and dusty air, produces a sensation of thirst that may be appeased by moistening the membrane with a small amount of water not in itself sufficient to relieve a genuine water need of the body. Prolonged deprivation of water affects the water content of all the tissues and gives rise to sensations not of simple thirst alone, but of actual pain and suffering. Under these conditions it is probable that sensory nerves are stimulated in many tissues, and in addition the metabolism of the nervous system is directly affected by loss of water.

Nausea.—This sensation may be due to stimulation from the stomach, to substances in the blood, and to impulses coming from various parts of the body, *e.g.*, the organs of sight, taste and smell.

TASTE

Aside from the conditions which are always necessary for sense-perception,—*viz.*, proper organs for receiving, communi-

cating, and perceiving the sensory impulse,—there must be present a savory substance which must be in solution. The solution in the case of dry substances is effected by saliva. It is also necessary that the surface of the organs of taste shall be moist. The substances which excite the special sensation of *taste*, act by producing a change in the taste buds and this change furnishes the required stimulant.

Organs of taste.—The special organs of the sense of taste are end-organs of nerve filaments which are derived from the trigeminal, facial, and glossopharyngeal nerves. These end-organs are called *taste buds* and are situated chiefly on the surface of the tongue, though some are scattered over the soft palate, fauces, epiglottis, and even the vocal folds.

The tongue.—The tongue is a freely movable muscular organ

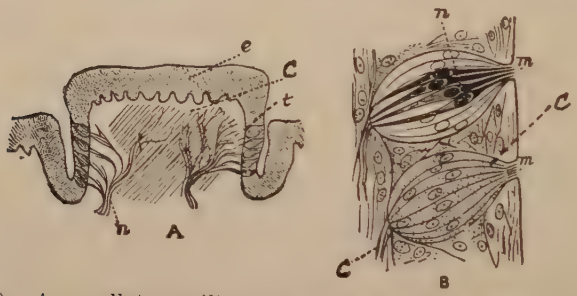


Fig. 220.—*A*, a vallate papilla cut lengthwise; *e*, epidermis; *c*, corium; *t*, taste-buds; *n*, nerve-fibers. *B*, the two taste-buds at *t* more highly magnified, the lower as seen from the outside showing *c*, the outer or supporting cells; the upper as seen in section showing *n*, four inner cells with processes *m*, projecting at the mouth of the bud. (From Elementary Physiology by Thomas H. Huxley.)

consisting of two distinct halves united in the center. The root of the tongue is directed backward and is attached to the hyoid bone by several muscles. It is connected with the epiglottis by three folds of mucous membrane, and with the soft palate by means of the anterior pillars of the fauces.

Papillæ of the tongue.—The tongue is covered and lined with mucous membrane. The mucous membrane on the under surface is similar to that lining the rest of the mouth, but the mucous membrane on the upper surface is studded with papillæ. The papillæ are projections of connective tissue, covered with stratified epithelium and contain a loop of capillaries among which nerves are distributed. They give the tongue its characteristic rough appearance. Of these papillæ there are four varieties:—

(1) Vallate (Circumvallate) papillæ are the largest, are circular in shape, and form a V-shaped row near the root of the tongue with the open angle of the V turned toward the lips. They serve to secrete mucin and contain *taste buds*.

(2) Fungiform papillæ are the next in size, and are so named because they resemble fungi in shape. They are found principally on the tip and sides of the tongue.

(3) Filiform papillæ are found all over the tongue, except at

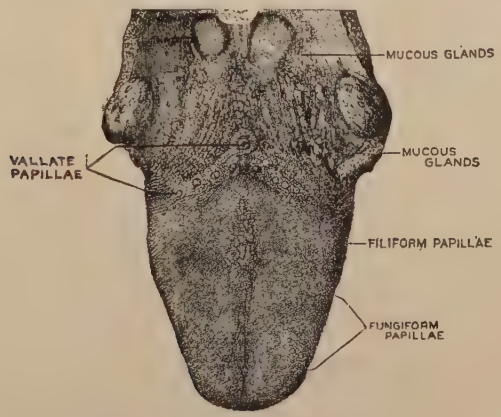


FIG. 221.—THE UPPER SURFACE OF THE TONGUE. (Sapper.)

the root, and bear on their free surface delicate brush-like processes which seem to be specially connected with the sense of touch, which is very highly developed on the tip of the tongue.

(4) Simple papillæ similar to those of the skin cover the larger papillæ and the whole of the mucous membrane of the tongue.

Nerve supply of the tongue.—The nerve fibers which terminate in the taste buds are: (1) filaments of the lingual nerve, which is a branch of the fifth or trigeminal, (2) filaments of the chorda tympani, a branch of the seventh or facial, and (3) filaments of the ninth or glossopharyngeal nerve.[2] The twelfth or hypoglossal nerve is distributed to the tongue, but is a motor nerve and is not concerned in the sense of taste or touch.

Other sensations in the tongue.—The sense of touch is very highly developed here, and with it the sense of temperature, pain, etc. Upon these tactile and muscular senses to a great extent depends the accuracy of the tongue in many of its important uses —speech, mastication, deglutition, sucking.

[2] This is the generally accepted view, but other statements may be found in various text-books.

Classification of taste sensations.—Our taste sensations are very numerous, but four fundamental or primary sensations are recognized, namely—salty, bitter, acid and sweet. All other sensations are combinations of these, or combinations of one or more of them with sensations of odor, or with sensations derived from stimulation of other nerves in the tongue. The seemingly great variety of our taste sensations is due to the fact that we confuse them or combine them with simultaneous odor sensations. Thus the flavors in fruits are designated as tastes because they are experienced at the same time these objects are eaten. If we shut off the nasal cavities as by holding the nose, the so-called taste often disappears in large measure. Very disagreeable tastes are usually due to unpleasant odor sensations. Hence the practice of holding the nose when we wish to swallow a nauseous dose. On the other hand, some volatile substances which enter the mouth through the nostrils and stimulate the taste buds are interpreted by us as odors. The odor of chloroform is largely due to stimulation of the sweet taste in the tongue.

SMELL

The first essentials are a special nerve and nerve center, the changes in whose condition are perceived as sensations of odor. No other nerve structure is capable of such sensations, even when acted on by the same cause. The special organs for this sense must be in their normal condition, and a stimulus (odor) must be present to excite them.

Olfactory nerves.—The olfactory nerves are the special nerves of the sense of smell, and are spread out in a fine network over the surface of the superior nasal conchæ and the upper third of the septum. The nerves end in special organs known as olfactory cells, which lie among supporting epithelial cells of a columnar shape. Each cell bears on its free end a tuft of six to eight hair-like processes. At the free edge of the cells there is a limiting membrane through which the olfactory hairs project. The central portions of the olfactory cells are prolonged as nerve fibers into a mass of gray matter, called the *olfactory bulb*, which rests upon the cribriform plate of the ethmoid bone. From the olfactory bulb other fibers extend inward and connect with various centers in the cerebrum, thus allowing sensations of smell to serve as a stimulus for the recall of other sensations, and for the promotion of reflex responses. An important example of reflex

response is the secretion of saliva and gastric fluid induced by the odor of food.

The nerves which ramify over the lower part of the lining membrane of the nasal cavity are branches of the fifth or trigeminal nerve. These nerves furnish the tactile sense and enable us to perceive, by the nose, the sensations of cold, heat, tickling, pain, and tension or pressure. It is this nerve which is affected by strong irritants, such as ammonia or pepper.

Odors are caused either by minute particles of solid matter or by gases which are in the atmosphere, and they must be capable of solution in the secretion of the lining membrane. Odorous particles in the air, pa: :ng through the lower, wider air passages.

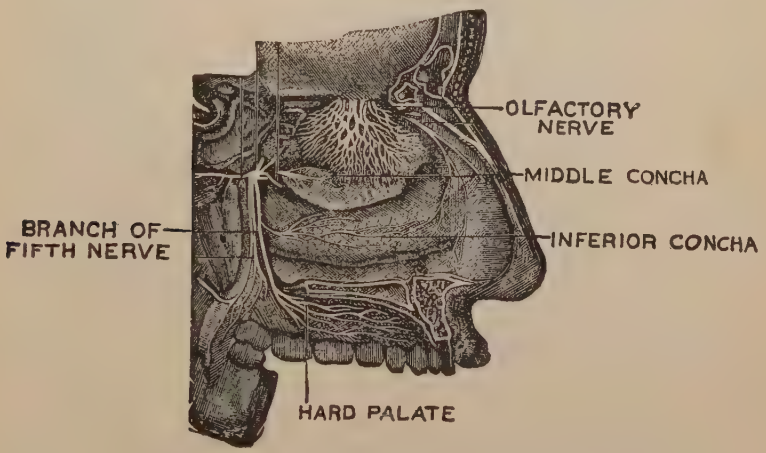


FIG. 222.—VERTICAL LONGITUDINAL SECTION OF NASAL CAVITY.

pass by diffusion into the higher, narrower, nasal chambers, and falling on the membrane which is provided with olfactory hairs, produce sensory impulses which, ascending to the brain, give rise to the sensation of smell.

If we wish to smell anything particularly well, we sniff the air up into the higher nasal chambers, and thus bring the odoriferous particles more closely into contact with the olfactory nerves. Odors can also reach the nose by way of the mouth. Many flavors of food are really odor, rather than gustatory sensations and we become aware of them just after swallowing. During swallowing the posterior nares are closed by the soft palate, which then opens, permitting odoriferous molecules to reach the sensory epithelium of the nose, through the wide posterior nares.

Each substance we smell causes its own particular sensation, and we are not only able to recognize a multitude of distinct odors, but also to distinguish individual odors in a mixed smell. These odors are difficult to classify, *i.e.*, it is not possible to pick out what might be called the fundamental odor sensations. One classification groups odors into (1) pure odors, (2) odors mixed with sensations from the mucous membrane of the nose, and (3) odors mixed or confused with tastes. The pure odors are further subdivided into nine classes, namely, ethereal, aromatic, fragrant, ambrosial, garlic, burning odors, goat odors, repulsive odors, and nauseating or fetid odors.

The sensation of smell develops quickly after the contact of the odoriferous stimulus, and may last a long time. When the stimulus is repeated, the sensation very soon dies out, the sensory terminal organs quickly becoming exhausted. This accounts for the fact that one may easily become accustomed to foul odors and is an advantage when foul odors have to be endured. On the other hand, it emphasizes the importance of acting on the first sensation of a disagreeable odor, so as not to become accustomed to it.

The olfactory center in the brain is widely connected with other areas of the cerebrum, so that the sense of smell is a component of many phases of psychic life, and is closely connected with bodily appetites and sexual reflexes.

HEARING

The auditory apparatus consists of: (1) the external ear; (2) the middle ear; (3) the internal ear; and (4) the acoustic or auditory nerve.

External ear.—The external ear consists of an expanded portion named **auricle,** or **pinna,** and the **auditory** or **meatus canal.**

The **auricle** projects from the side of the head. With the exception of the lower portion, it consists of a framework of cartilage, containing some fatty tissue and a few muscles. In the lower portion, which is called the lobe, the cartilage is replaced by connective tissue. The auricle is covered with skin, and joined to the surrounding parts by ligaments and a few muscles. It is very irregular in shape. The central depression, the concha, serves to some extent to collect sound waves.

The **auditory canal** or **meatus** is a tubular passage, about an inch (2.5 cm.) in length, leading from the concha to the drum-

membrane. The exterior portion of the wall of the auditory canal consists of cartilage, which is continuous with that of the auricle; the posterior portion is hollowed out of the temporal bone. This canal is slightly curved upon itself so as to be higher in the middle than at either end, and its direction is forward and inward. Lifting the auricle upward and backward tends to straighten the canal; except in the case of children it is best straightened by

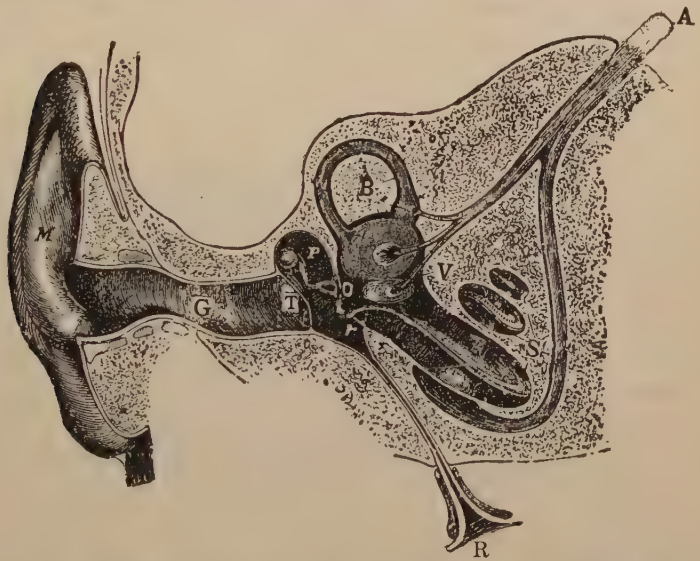


FIG. 223.—SEMI-DIAGRAMMATIC SECTION THROUGH THE RIGHT EAR. *M*, concha; *G*, meatus or external auditory canal; *T*, tympanic, or drum-membrane; *P*, tympanic cavity or middle ear; *o*, fenestra vestibuli; *r*, fenestra cochlea. Extending from *T* to *o* is seen the chain of the tympanic bones; *R*, Eustachian tube; *V*, *B*, *S*, bony labyrinth; *V*, vestibule; *B*, semicircular canal; *S*, cochlea; *A*, auditory nerve dividing into branches for vestibule, semicircular canal, and cochlea.

drawing the auricle downward and backward. It is lined by a prolongation of the skin, which in the outer half of the canal is very thick and not at all sensitive, and in the inner half is thin and highly sensitive. Near the orifice the skin is furnished with a few hairs, and farther inward with modified sweat-glands, and the ceruminous glands, which secrete a yellow, pasty substance called cerumen, or earwax. These hairs and the cerumen serve to protect the ear from the entrance of foreign substances.

Membrana tympani (membrane of the drum).—The auditory canal is separated from the tympanic cavity by a membrane known as the tympanic membrane or eardrum. This consists of

a thin layer of fibrous tissue covered externally with skin and internally with mucous membrane.

Middle ear.—The middle ear, or tympanic cavity is a small, irregular bony cavity, situated in the petrous portion of the temporal bone. It is so small that probably five or six drops of water would completely fill it. It is separated from the external auditory canal by the tympanic membrane, and from the internal ear by a very thin,[3] bony wall in which there are two small openings; the *fenestra vestibuli* (*ovalis*), and the *fenestra cochleæ* (*rotunda*). In the dorsal (posterior) wall there is an opening into the mastoid antrum and mastoid cells and because of this, infection of the middle ear may extend into the mastoid cells and cause mastoiditis[4]. In the ventral (anterior) wall is an opening into the Eustachian tube, a small canal which leads to the naso-pharynx. Thus there are five openings in the middle ear, namely, the opening between it and the auditory canal; the fenestra vestibuli and the fenestra cochleæ which connect with the internal ear; the opening into the mastoid cells, and the opening into the Eustachian tube. The walls of the tympanic cavity are lined by mucous membrane which is continuous anteriorly with the mucous membrane of the Eustachian tube and posteriorly with that of the mastoid antrum and mastoid cells.

Ossicles.—Stretching across the cavity of the middle ear from the tympanic membrane to the fenestra vestibuli are three tiny, movable bones, named, because of their shapes the **malleus,** or hammer, the **incus,** or anvil, and the **stapes,** or stirrup. The handle of the hammer is attached to the tympanic membrane, and the opposite end or head of the hammer is attached to the base of the anvil. The long process of the anvil is attached to the stapes, and the footpiece of the stapes is attached to the fibrous membrane that is stretched across the fenestra vestibuli. These little bones are held in position, attached to the tympanic-membrane, to each other, and to the membrane of the fenestra vestibuli by minute ligaments and muscles. They are set in motion with every movement of the tympanic membrane. Vibrations of the membrane are communicated to the hammer, taken up by the anvil, and transmitted to the stirrup, which rocks in the fenestra vestibuli, and is therefore capable of transmitting to the fluid in the cavity of the labyrinth the impulses which it receives.

[3] Only about 1/24 inch in thickness.

[4] The temporal bone at this point is very porous, and any suppurative process is exceedingly dangerous, for the infection may travel inward and involve the brain.

The Eustachian tube.—The Eustachian or auditory tube connects the cavity of the middle ear with the pharynx. It is about one and one-half inches (37 mm.) long, about one-eighth of an inch (3 mm.) wide, and flares out into a wide opening as it enters the pharynx. Generally this opening is kept closed by the tissues of the pharynx in order that the inner ear shall not receive the vibrations of the vocal folds too directly. On swallowing, the pharyngeal orifice of the Eustachian tube is opened. In this way the pressure of air in the middle ear, and hence against the tympanic membrane from the inside, is kept equal to that against it from the outside. In cases of infection of the throat, the Eustach-

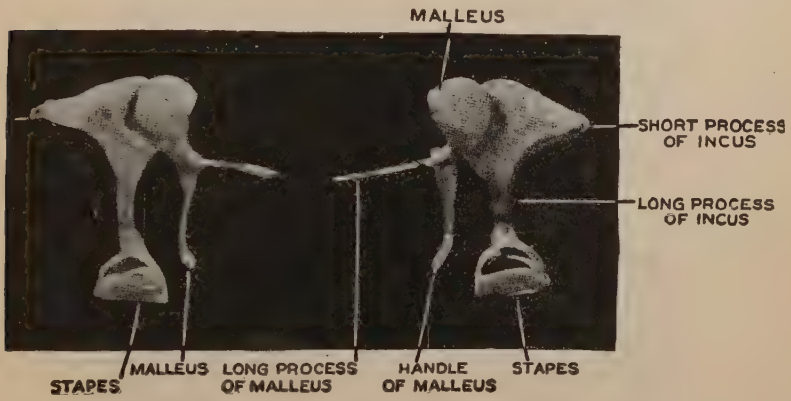


FIG. 224.—OSSICLES OF THE TYMPANUM, × 4. (Flint.)

ian tube may be temporarily occluded, in which case pressure in the middle ear and hence against the tympanic membrane from the inside, becomes unlike that against it from the outside, and the membrane bulges in or out as the case may be. Unless corrected this condition may become permanent and cause difficulty in hearing.

Internal ear.—The internal ear, or labyrinth, receives the ultimate terminations of the auditory nerve, and is, therefore, the essential part of the organ of hearing. It consists of a *bony labyrinth,* which is composed of a series of peculiarly shaped cavities, hollowed out of the petrous portion of the temporal bone, and named from their shape:—

(*a*) The vestibule.
(*b*) The cochlea (snail-shell).
(*c*) The semicircular canals.

Within the bony labyrinth is a *membranous labyrinth,* having

the same general form as the cavities in which it is contained though considerably smaller, being separated from the bony walls by a quantity of fluid called the perilymph. It does not float loosely in this liquid because in some places it is attached to the bone by bands of fibrous tissue. The cavity within the membrane is filled with a fluid called *endolymph*.

The **vestibule** is the central cavity behind the cochlea and in front of the semicircular canals. It communicates with the middle ear by means of the fenestra vestibuli in its outer wall. The vestibular membrane does not conform to the shape

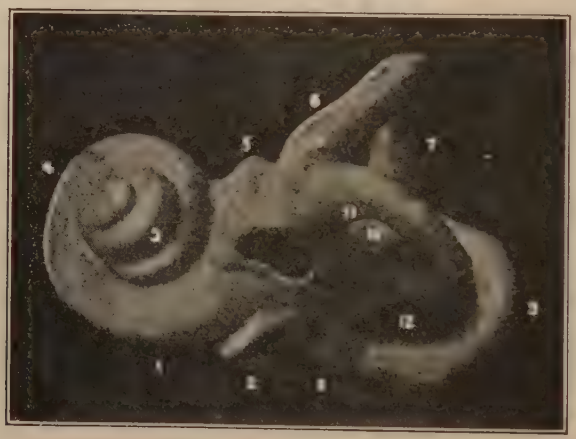


Fig. 225.—The Left Bony Labyrinth of a New-born Child, Forward and Outward View, × 4.

1, the wide canal, the beginning of the spiral canal of the cochlea; 2, the fenestra cochleæ; 3, the second turn of the cochlea; 4, the final turn of the cochlea; 5, the border of the bony wall of the vestibule, situated between the cochlea and the semicircular canals; 6, the superior, semicircular canal; 7, the portion of the semicircular canal bent outward; 8, the posterior, semicircular canal; 9, the portion of the posterior connected with the superior semicircular canal; 10, the point of junction of the superior and the posterior semicircular canals; 11, the ampulla ossea externa; 12, the lateral semicircular canal. (Flint.)

of the bony cavity but consists of two small sacs, called respectively the *saccule* and the *utricle*. The saccule is in front and nearer the cochlea, and the utricle is back and nearer the semicircular canals. These sacs are connected by a tube called the endolymph duct, which is shaped like a Y. The walls of these sacs contain numerous columnar cells provided with stiff hairs which project into the endolymph. These cells are in relation with fibers of the vestibular branch of the auditory nerve and

serve as end-organs. Among these hair cells rest several small crystals of calcium carbonate which are called *otoliths* (ear stones).

The **cochlea** opens from the front end of the vestibule and saccule. It resembles a snail-shell and consists of a spiral tube of two and three-quarter turns around a hollow, conical, central pillar called the *modiolus*[5], from which a thin lamina[6] of bone projects like a spiral shelf about halfway toward the outer wall of the tube.

The *basilar membrane* stretches from the free border of the lamina to the outer wall of the bony cochlea, and completely divides its cavities into two passages or *scalæ*.[7] The upper is the *scala vestibuli* which terminates at the *fenestra vestibuli*, and the lower is the *scala tympani* which terminates at the *fenestra cochleæ*. On the basilar membrane the sound-sensitive epithelium of the organ of Corti[8] is located. This consists of a large number of rod-shaped cells and hair cells. Some 24,000 so-called "auditory strings" lie embedded in the basilar membrane. These "strings" are of varying lengths and one theory of hearing claims that they are sensitive to air vibrations of varying frequency. The modiolus contains bipolar nerve cells and the peripheral branches pass through the numerous foramina and are distributed to the basilar membrane and the organ of Corti.

The **semicircular canals** are three bony canals lying above and behind the vestibule, and communicating with it by five openings, in one of which two tubes join. They are known as the *superior*, *posterior*, and *lateral* canals, and their position is such that each one is at right angles to the other two. One end of each tube is enlarged and forms what is known as the ampulla. Each ampulla contains an area of sensory epithelium, consisting of cells with hair-like processes which project into the endolymph. Some of the terminations of the vestibular branch of the auditory nerve are distributed around these cells.

The acoustic or auditory nerve.—The acoustic nerve is a sensory nerve and contains two distinct sets of fibers, which differ in their function, origin, and destination. One set of fibers is known as the cochlear division and the other as the vestibular.

The fibers of the **cochlear nerve** arise from bipolar cells that are situated in the modiolus of the cochlea. The peripheral fibers

5 Modiolus [from the Latin *the nave of a wheel*].
6 Lamina [from the Latin *a thin plate or scale*].
7 Scala [from the Latin *a staircase*].
8 Named after Corti, an Italian anatomist, died 1813.

pass through the foramina of the modiolus or lamina, and connect with the cells of the organ of Corti. The central fibers pass through the internal auditory meatus to the floor of the fourth ventricle and there connect with the cochlear root of the auditory nerve. Their impulses are then transmitted to the auditory centers in the temporal lobe of the cerebrum. The nerve fibers which pass from the ear to the auditory centers are not continuous strands, as there are several relays of ganglia in which the axons of some cells form synapses with the dendrites of other cells.

The fibers of the **vestibular nerve** have their origin in a nucleus of bipolar cells situated in the upper part of the outer end of the internal auditory meatus. The peripheral fibers are divided into three branches and are distributed around the hair cells of the saccule, utricle, and the ampulla of the semicircular canals. The central fibers join the fibers from the cochlear nerve and end in the floor of the fourth ventricle. Here they connect with a nucleus from which some fibers extend to the cerebellum, and others pass down the spinal cord to form connections with motor centers of the spinal nerves.

In the medulla most of the fibers from each ear cross to the opposite side, and therefore injury to the temporal lobe of one side affects the hearing in the ear on the opposite side, more than the hearing in the ear of the side affected. Destruction of the auditory centers in both lobes will result in defective hearing, but oftentimes the deafness is not complete or permanent. Because of this it is thought that the relay stations are capable of acting as subordinate auditory centers, *i.e.*, of transferring auditory impulses to the association areas.

Physiology of hearing.—All bodies which produce sound are in a state of vibration, and communicate their vibrations to the air with which they are in contact.

When these air waves, set in motion by sonorous bodies, enter the external auditory canal, they set the drum-membrane vibrating; stretched membranes taking up vibrations from the air with great readiness. These vibrations are communicated to the chain of tiny bones stretched across the middle ear, and their oscillations cause the membrane leading into the internal ear (fenestra vestibuli) to be alternately pushed in and drawn out; the vibrations are in this way transmitted to the perilymph. The movements of the perilymph, in rhythm like those of the air in some unknown way stimulate the nerve-endings in the organ of Corti,

and from these impulses are conveyed to the center of hearing in the cerebrum. Various theories are held regarding the manner in which the organ of Corti is stimulated. One generally accepted is that the fibers of the basilar membrane respond to vibrations of different rates. The vibration of each fiber of the basilar membrane causes the stimulation of the attached hair cell and its nerve fiber. Abnormal conditions in any part of the auditory mechanism stimulate the auditory nerve and give rise to noises that are described as rushing, roaring, humming, and ringing.

The sense of equilibrium.—Among the various means (such as sight, touch, and muscular sense) whereby we are enabled to maintain our equilibrium, coördinate our movements, and become aware of our position in space, one of the most important is the action of the vestibule and semicircular canals. Though these structures are found in the inner ear and communicate with the cochlea, it is now thought that they are not connected with the sense of hearing. As a result of much experimental work, many facts regarding the effects of injury to the semicircular canals have been accumulated, but it is difficult to interpret these facts and several theories have been proposed. One theory is that movements of the head set up movements in the endolymph of the canal, and these act as stimuli to the nerve endings around the hair cells.

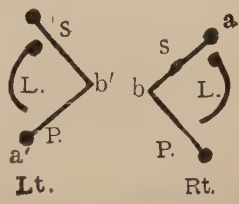


FIG. 226.—DIAGRAM SHOWING RELATIVE POSITION OF THE PLANES IN WHICH THE SEMICIRCULAR CANALS LIE. *Rt.*, right ear; *Lt.*, left ear; *S*, superior canal; *P*, posterior canal; *L*, lateral canal; *a*, ampulla of *Rt.* superior canal; *a′*, ampulla of *Lt.* posterior canal.

The canals are so arranged (Fig. 226) that any movement of the head causes an increase in the pressure of the endolymph in one ampulla, and a corresponding diminution in the ampulla of the parallel canal on the opposite side. Thus, a nodding of the head to the right would cause a flow of the endolymph from a to b in the right superior canal, but from b' to a' in the left posterior canal. Hence the pressure upon the hairs is decreased in a, but increased in a'. Such stimulations of the sensory hairs are transmitted by the dendrites of the vestibular nerve, through the cell bodies of the vestibular ganglion and the axons of the auditory nerve, to the cerebellum. It is thought that the cerebellum is the center in the brain which interprets and adjusts the impulses that arise from stimulation of the sensory nerves

concerned with muscular sense. It is also the center that interprets and adjusts impulses that arise from stimulation of the vestibular nerve-endings. From this it is thought that the cerebellum controls equilibrium.

SIGHT

The visual apparatus consists of the eyeballs, the optic nerves, and the nerve centers in the brain. In addition to these essential organs, there are accessory organs which are necessary for the protection and functioning of the eyeball.

Accessory organs of the eye.—Under this heading we class: (1) eyebrows, (2) eyelids, (3) conjunctiva, (4) lacrimal apparatus, (5) muscles of the eyeball, and (6) the fascia bulb.

Eyebrows.—The eyebrows are two thickened ridges of skin, covered with short hairs. They are situated on the upper border of the orbits, and protect the eyes from too vivid light, perspiration, etc.

Eyelids.—The eyelids (or palpebræ) are two movable folds which when closed partially or wholly cover the eyes. They are covered externally by the skin, and internally by a mucous membrane, the conjunctiva, which is reflected from them over the globe of the eye. They are composed of muscle fibers and connective tissue. The latter is dense and fibrous and is known as the *tarsal plates*. The upper lid is attached to a small muscle which is called the elevator of the upper lid (*levator palpebræ superioris*), and arranged as a sphincter around both lids is the *orbicularis oculi* muscle, which closes the eyelids.

The slit between the edges of the lids is called the palpebral fissure. It is the size of this fissure which causes the appearance of large and small eyes, as the size of the eyeball itself varies but little. The outer angle of this fissure is called the lateral commissure (*canthus*); the inner angle, the medial commissure (*canthus*).

The eyelids are obviously provided for the protection of the eye; movable shades which (1) close the eyes during sleep, (2) protect the eyes from a bright light and foreign objects, and (3) spread the lubricating secretions of the eye over the surface of the eyeballs.

Eyelashes and sebaceous glands.—From the margin of each eyelid, a row of short thick hairs—the eyelashes—project. The follicles of the eyelashes receive a lubricating fluid from the sebaceous glands which open into them. If this secretion be-

comes infected a stye results. A stye therefore is comparable to a pimple or furuncle resulting from the infection of retained sebaceous fluid in other regions of the skin.

Embedded in the tarsal cartilage of each eyelid is a row of elongated sebaceous glands—the tarsal[9] or Meibomian glands,—the ducts of which open on the edge of the eyelid. The secretion of these glands lubricates their edges and prevents adhesion of the eyelids.

Conjunctiva.—The mucous membrane which lines the eyelids and is reflected over the forepart of the eyeball is called conjunctiva. It is continuous with the lining membrane of the ducts of the tarsal glands, the lacrimal ducts, lacrimal sac, naso-lacrimal duct and nose.

Lacrimal apparatus.—This apparatus consists of (1) the lacrimal gland, (2) lacrimal ducts, (3) the lacrimal sac and caruncle, (4) the lacrimal canal, and (5) the naso-lacrimal duct.

The *lacrimal gland* is a compound gland, and is lodged in a depression of the frontal bone at the upper and outer angle of the orbit. It is oval in form, about the size and shape of an almond and consists of two portions, a superior and inferior which are partially separated by a fibrous septum.

Seven to twelve minute *ducts* lead from the gland to the surface of the conjunctiva of the upper lid. The secretion (tears) is usually just enough to keep the eye moist, and after passing over the surface of the eyeball is sucked through the punctæ into two tiny *lacrimal ducts* and conveyed into the *lacrimal sac* at the inner angle of the eye. The *lacrimal sac* is the expanded upper end of the *naso-lacrimal* duct, a small canal that opens into the nose. In the center of the lacrimal sac is a small pink elevation known as the *lacrimal caruncle.*

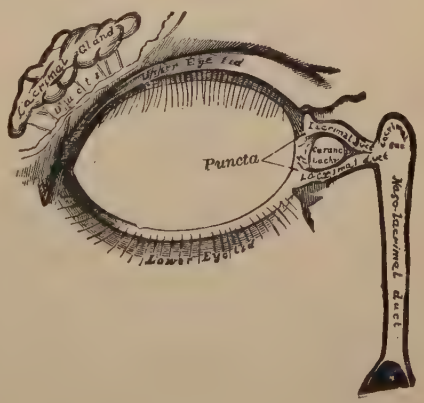


FIG. 227.—THE LACRIMAL APPARATUS.

[9] By everting the eyelids, these glands may be seen through the conjunctiva lying in parallel rows.

The lacrimal glands secrete tears. This secretion is a dilute solution of various salts in water, which also contains small quantities of mucin. The ducts leading from the lacrimal glands carry it to the eyeball, and the lids spread it over the surface. Ordinarily this secretion is evaporated, or carried away by the naso-lacrimal duct as fast as formed, but under certain circumstances, as when the conjuctiva is irritated, or when painful emotions arise in the mind, the secretion of the lacrimal gland exceeds the drainage power of the naso-lacrimal duct, and the fluid, accumulating between the lids, at length overflows and runs down the cheeks. The purpose of the lacrimal secretion is to keep the surface of the eyes moist, and to help remove foreign bodies, microörganisms, dust, etc. It is slightly antiseptic. The secretion is increased by (1) foreign bodies (molecules of volatile gases, liquids, dust, microörganisms) that come in contact with the eye or lids, (2) irritation of the nasal mucous membrane, (3) a bright light, and (4) emotional states. Inflammation from the nose may spread to the naso-lacrimal and lacrimal ducts, blocking them, and thus cause a slow dropping of tears from the inner angle of the eye.[10]

Muscles of the eye.—For purposes of description the muscles of the eye are divided into two groups: (1) intrinsic, and (2) extrinsic. The intrinsic muscles are the ciliary muscle, and the muscles of the iris.[11] The extrinsic muscles hold the eyeball in place and control its movements. They include the four straight or recti and the two oblique, described on page 85. The recti muscles are so arranged that the superior and inferior oppose each other, the internal and external do likewise. This action is comparable to the opposed action of the flexors and extensors on the arms and legs, and insures accuracy of movement. Sometimes these muscles (particularly the internal and external recti) are unequal in length or strength, the equilibrium of the opposed muscles is upset, and the eye is then turned in the direction of the stronger muscle, producing a squint or strabismus.

Nerves of the eye.—The nerves which are supplied to the eye are: (1) the optic nerve, concerned with vision only; (2) the oculomotor nerve which supplies (*a*) the internal, superior and inferior recti, and the inferior oblique muscles, and (*b*) the ciliary muscle, and the circular muscle of the iris; (3) the trochlear nerve

[10] The lacrimal glands do not develop sufficiently to secrete tears until about the fourth month of life, hence the need for protecting a baby's eyes from bright lights, dust, etc.

[11] See page 481.

which controls the superior oblique muscle; (4) the abducent which controls the external rectus; and (5) the ophthalmic, which is a branch of the trigeminal nerve, supplies general sensation such as pressure, muscle sense and pain. (6) Sympathetic fibers are supplied to the ciliary muscle and the radial muscle of the iris.

The orbits.—The orbits are the bony cavities in which the eyeballs are contained.

Seven bones assist in the formation of each orbit, namely frontal, malar, maxilla, palatine, ethmoid, sphenoid, and lacrimal. As three of these bones are mesial (frontal, ethmoid, and sphenoid) there are only eleven bones forming both orbits.

The orbit is shaped like a funnel; the large end directed outward and forward forms a strong bony edge for protecting the

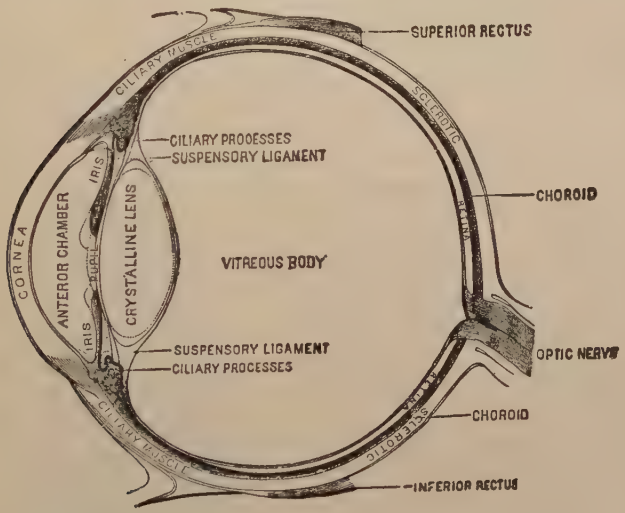


FIG. 228.—DIAGRAMMATIC SECTION OF THE EYE. (Flint.)

eyeball from injury. The small end is directed backward and inward and is pierced by a large opening—the optic foramen—through which the optic nerve and the ophthalmic artery pass from the cranial cavity to the eye. A larger opening to the outer side of the optic foramen—the sphenoidal fissure—provides a passage for the ophthalmic vein and the nerves which carry impulses to and from the muscles, *i.e.*, the oculomotor, the trochlear, the abducent, and the ophthalmic. Each orbit contains the eyeball, muscles, nerves, vessels, lacrimal glands, fat,

the fascia bulb, and fascia that hold these structures in place. The inner portion is lined with fibrous tissue and contains a pad of fat which serves as a cushion for the eyeball. During many forms of illness the body fat is oxidized at an unusual rate. Under such conditions the orbital fat becomes diminished, and the eyeballs sink in the orbits.

Fascia bulb (capsule of Tenon).—Between the pad of fat and the eyeball is a serous sac—the fascia bulb—which envelops the eyeball from the optic nerve to the ciliary region and forms a socket in which the eyeball rotates.

The eyeball.—The eyeball is spherical in shape, but its transverse diameter is less than the antero-posterior, so that it projects anteriorly, and looks as if a section of a smaller sphere had been engrafted on the front of it.

The eyeball is composed of three coats, or tunics. From within outward these are:—

(1) Fibrous: (*a*) sclera; (*b*) cornea.
(2) Vascular: (*a*) choroid; (*b*) ciliary body; (*c*) iris.
(3) Visual: retina.

It contains three refracting media. These are:—

(1) Aqueous.
(2) Crystalline lens and capsule.
(3) Vitreous.

Fibrous tunic.—The fibrous tunic is formed by the sclera and cornea. (*a*) The *sclera*, or *white of the eye*, covers the dorsal five-sixths of the eyeball. It is composed of a firm, unyielding, fibrous membrane, thicker behind than in front, and serves to protect the delicate structures contained within it, and maintain the shape of the eyeball. It is opaque; white and smooth externally, and behind is pierced by the optic nerve. Internally it is brown in color and is separated from the choroid by a lymph space. It is supplied with few blood-vessels. Its nerves are derived from the ciliary nerve.

(*b*) The *cornea* covers the ventral sixth of the eyeball. It is directly continuous with the sclera, which, however, overlaps it slightly above and below, as a watch crystal is overlapped by the case into which it is fitted. The cornea, like the sclera, is composed of fibrous tissue, which is firm and unyielding, but, unlike the sclera, it has no color, and is perfectly transparent; it has been aptly termed the "window of the eye." The cornea is well supplied with nerves (derived from the ciliary) and lymph-spaces,

but is destitute of blood-vessels, so that it is dependent on the lymph contained in the lymph-spaces for nutriment.

Vascular tunic.—The vascular tunic consists of the choroid, the ciliary body and the iris, from behind forward in the order named. (*a*) The *choroid*, or vascular coat of the eye, is a thin, dark brown membrane lining the inner surface of the sclera. It consists of a dense capillary plexus and small arteries and veins carrying blood to and from the plexus. Between these vessels are pigment cells which with other cells form a network or stroma. The blood vessels and pigment cells render this membrane dark and opaque, so that it darkens the chamber of the eye by preventing the reflection of light. It extends to the ciliary body.

(*b*) The *ciliary body* is located between the choroid and the iris, and consists of the ciliary processes, and the ciliary muscle. Just behind the edge of the cornea, the choroid is folded inward and arranged in radiating folds, like a plaited ruffle, around the lens. There are about seventy of these folds, and they constitute the ciliary processes. They are well supplied with nerves and blood-vessels, and also support a muscle, the ciliary (ciliaris) muscle. The fibers of this muscle arise from the sclera near the cornea, and extending backward are inserted into the outer surface of the ciliary processes and the choroid. The action of this muscle determines the position of the lens.

FIG. 229.—SEGMENT OF THE IRIS, CILIARY BODY, AND CHOROID. Viewed from the internal surface. (Gerrish.)

(*c*) The *iris* (*iris*, rainbow) is a circular, colored disc suspended in the aqueous humor in front of the lens and behind the cornea. It is attached at its circumference to the ciliary processes, with which it is practically continuous, and is

also connected to the sclera and cornea at the point where they join one another. Except for this attachment at its circumference, it hangs free in the interior of the eyeball. In the middle of the iris is a circular hole, the *pupil*, through which light is admitted into the eye chamber. The iris is composed of connective tissue containing branched cells, numerous blood-vessels and nerves. The color of the eye is related to the number and size of pigment bearing cells in the iris. If there is no pigment or very little the eye is blue; with increasing amounts of pigment the eye is gray, brown or black. It also contains two sets of muscles. One set is arranged like a sphincter with its fibers encircling the pupil, and is called the *contractor of the pupil.*[12] The other set consists of fibers which radiate from the pupil to the outer circumference of the iris, and is called the *dilator of the pupil.*[13] The action of these muscles is antagonistic.

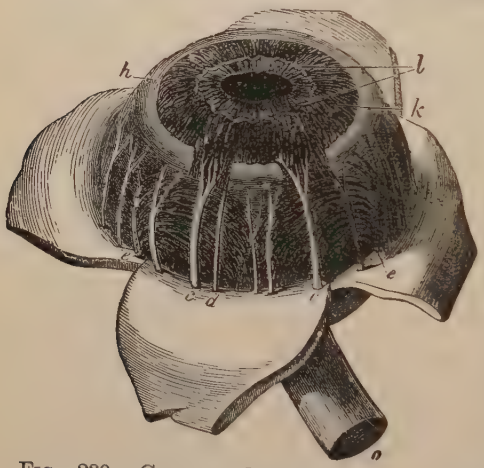


FIG. 230.—CHOROID MEMBRANE AND IRIS EXPOSED BY THE REMOVAL OF THE SCLERA AND CORNEA. Twice the natural size. *d*, one of the segments of the sclera thrown back; *l* and *k*, iris; *c*, ciliary nerves; *e*, one of the veins of the choroid. The ciliary muscle is crossed by the line from *k*, and should be represented as radiating. (Collins.)

The posterior surface of the iris is covered by layers of pigmented epithelium named *uvea* from its color being like that of a ripe grape. It is designed to prevent the entrance of light.

Function of the iris.—The function of the iris is to regulate the amount of light entering the eye, and thus assist in obtaining clear images. It is enabled to perform this function by the action of the muscles described above, as their contraction or relaxation determines the size of the pupil. When the eye is accommodated[14] for a near object, or stimulated by a bright light, the sphincter muscle contracts and diminishes the size of the pupil. When, on the other hand, the eye is accommodated for a distant

[12] Sphincter pupillæ. [13] Dilator pupillæ [14] See page 488.

object, or the light is dim, the dilator muscle contracts, and the pupil is pulled wider open.

Visual tunic.—The retina, the innermost coat of the eyeball, is a delicate nervous membrane which receives the images of external objects and transfers the impressions evoked by them to

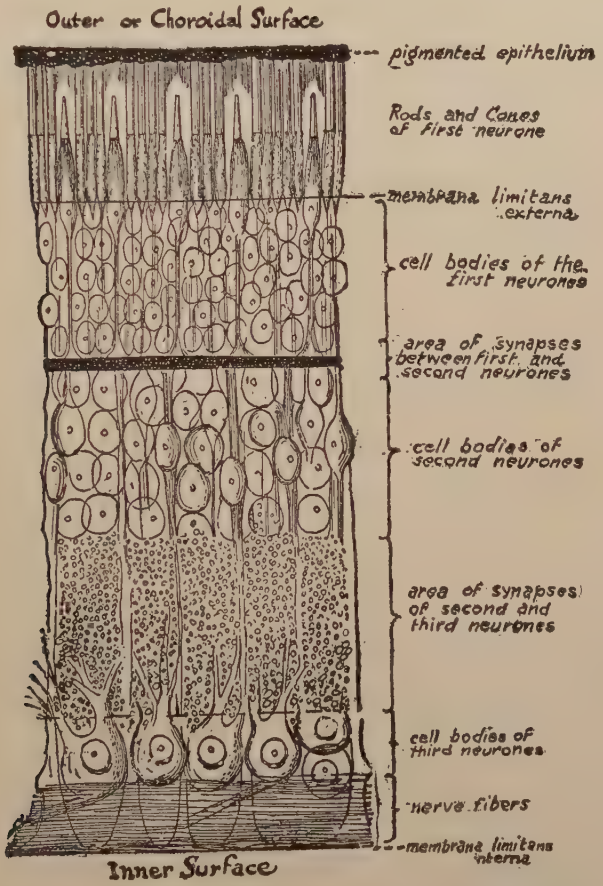

Outer or Choroidal Surface
pigmented epithelium
Rods and Cones of first neurone
membrana limitans externa
cell bodies of the first neurones
area of synapses between first and second neurones
cell bodies of second neurones
area of synapses of second and third neurones
cell bodies of third neurones
nerve fibers
membrane limitans interna
Inner Surface

FIG. 231.—DIAGRAMMATIC SECTION OF THE HUMAN RETINA.

the center of sight in the cortex of the cerebrum. It occupies the space between the choroid coat and the hyaloid membrane of the vitreous and extends forward almost to the posterior margin of the ciliary body where it terminates in an irregular wavy line known as the *ora serrata*. It consists of three sets of neurons so arranged that the cell bodies and processes form seven layers.

There are two limiting membranes, one membrane (membrana limitans interna) in contact with the vitreous layer, and the second (membrana limitans externa) marking the internal limit of the rod and cone layer.

The seventh layer is called the layer of rods and cones, and these act as end-organs for the optic nerve. It is thought that the perception of color is the function of the cones, while the rods are sensitive to light and darkness. This layer is covered by pigmented epithelium. To reach this layer rays of light pass through the cornea, lens, humors, and the entire thickness of the retina. The rods contain a pigment known as *rhodopsin* or visual purple, which is bleached by light, but is constantly regenerated, it is thought, by the pigment granules in the cells of the epithelial layer.

Blind spot.—The optic nerve pierces the eyeball not exactly at its most posterior point, but a little to the inner side. This point is insensitive to light and is called the blind spot. There are no rods and cones at this spot, and rays of light falling upon it produce no sensation. The arteria centralis retinæ and its vein pass into the retina along with the optic nerve.

Macula lutea.—There is one point of the retina that is of great importance, and that is the macula lutea, or yellow spot. It is situated about one-twelfth inch (2.08 mm.) to the outer side of the exit of the optic nerve, and is the exact center of the retina. In its center is a tiny pit,—*fovea centralis*,—which is the center of direct vision; that is, it is the part of the retina which is always turned towards the object looked at. From this point the sensitiveness of the retina grows less and less in all directions. At this point (fovea centralis) are found none of the fibers of the optic nerve, but a great increase in the number of cones, as well as in their size.

Refracting media.—(1) The *aqueous humor* fills the aqueous chamber; the latter is the space bounded by the cornea in front and by the lens, suspensory ligament, and ciliary body behind. This space is partially divided by the iris into an anterior and posterior chamber. The aqueous humor is a clear watery solution containing minute amounts of chlorid of sodium. It is believed that it is derived partly from the blood-vessels and partly by secretions of the neighboring epithelial cells.

(2) The *crystalline lens* is a transparent, refractive body, with convex anterior and posterior surfaces. It is placed directly be-

hind the pupil, where it is retained in position by the counterbalancing pressure of the aqueous humor in front, and the vitreous body behind, and by its own suspensory ligament formed in part by the hyaloid membrane, and in part by fibers derived from the ciliary processes. It is a fibrous body, enclosed in an elastic, non-vascular capsule. The posterior surface is considerably more curved than the anterior, and the curvature of each varies with the period of life. In infancy, the lens is almost spherical; in the adult, of medium convexity; and in the aged, considerably flattened. Its refractive power is much greater than that of the aqueous or vitreous body.

(3) The *vitreous body* a semi-fluid albuminous tissue enclosed in a thin membrane—the hyaloid membrane—fills the posterior four-fifths of the globe of the eyeball. The vitreous body distends the greater part of the sclera, supports the retina, which lies upon its surface, and preserves the spheroidal shape of the eyeball. Its refractive power, though slightly greater than that of the aqueous humor, does not differ much from that of water.

Perception of light and color.—It is commonly believed that all space is filled by ether, a medium so transparent and subtle that we are not able to perceive it by any of our senses. Waves started by the motion of the molecules of bodies (especially hot bodies like the sun) cause vibrations in this ether, and these vibrations are of varying lengths. Vibrations from .0004 mm. to .0008 mm. long, are called light and color waves. Those shorter than this are known as chemical or actinic rays; those much longer are electrical waves. When ether vibrations varying between .0004 to .0008 mm. enter the eye they cause chemical changes in the rods and cones which give rise to impulses that are carried by the optic nerve to the brain, and result in sight. Just how this is accomplished is not known, but the rods contain a kind of pigment which is called visual purple, and this as well as the pigment of the retina may function in these changes.

Refraction.—Light rays may be refracted or bent from their course. This is due to the fact that they travel at different rates in media of different density. For instance, light travels less rapidly in water than in air. For this reason where a ray of light in air strikes a body of water obliquely, it will be bent out of a straight line, as shown in Fig. 232. The light ray AC, instead of following the straight line AB, is bent on striking the surface of the denser medium, thereby being bent from its direct path toward C.

The bending is in proportion to the density of the medium. The cause of the refraction of oblique rays is that all the component rays do not reach the surface of the medium at the same time and those that enter first become retarded before those entering later. A ray of light which strikes a body of water perpendicularly will not be bent because all its component rays enter the water at the same time and hence all are equally retarded. The central components of a light wave enter our eyes perpendicularly, and the sides obliquely. For clear vision the oblique rays must converge and come to a focus with the central rays on the retina. The aqueous humor, the crystalline lens, and the vitreous humor form a system of refractory devices.

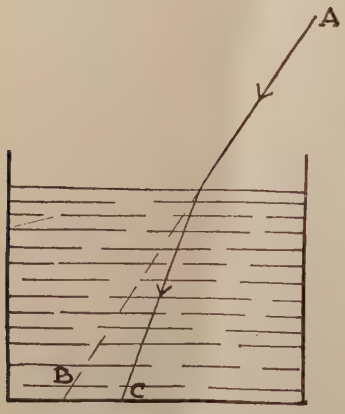


FIG. 232.—BENDING OF A BEAM OF LIGHT ENTERING WATER.

Vision.—Visible objects reflect light rays which fall upon them. These reflected rays are brought to a focus on the rods and cones of the retina, and the resulting nerve impulses are transmitted to the optic nerve and thence through various relay stations to the centers of vision in the occipital lobes of the cerebrum. From here it is believed the impulses are transmitted to the association areas where they awaken memories that enable us to interpret their meaning Several theories are advanced in explanation of the way in which rays of light stimulate the receptors of the optic nerve. One theory is that light rays bring about such changes in the visual purple that pictures are produced on the receptors similar to those made on the sensitive plate of a camera. This is questioned because the visual purple is absent from the cones of the fovea centralis which is the place of most acute vision and the part on which the light rays are focussed when the eyes are accommodated for near objects. Moreover, it has been found that the sensitiveness of the fovea centralis decreases in a dim light while that of the peripheral portion of the retina where the pigment is, increases. In a bright light we try to focus the object being looked at directly on the fovea, and the reflexes controlling accommodation help to bring this about. In a dim light

the tendency is to diverge the eyes and thus bring the image into the peripheral part of the retina. These facts support the assumptions that (1) in a bright light the cones of the fovea which are the chief receptors used need no sensitizing agent, but are directly affected by the light waves; (2) in a dim light the pupils are dilated and the light spreads over other parts of the retina, the visual purple is acted upon by the light waves and sensitizes the receptors in the peripheral portion so that they are stimulated by rays that otherwise would not affect them.

Processes necessary for binocular vision.—These processes are: (1) convergence or turning the eyes inward; (2) change in the size of the pupil; (3) accommodation; and (4) refraction.

(1) *Convergence.*—In binocular vision if an object is near the observer it is necessary to turn the eyes inward in order to place images on both retinas in about the same way. This is brought about by innervation of the internal recti muscles and is to some extent voluntary.

The optic chiasm.—The correspondence of the two retinæ and of the movements of the eyeballs is produced by a close connection of the nervous centers controlling these phenomena and by the arrangement of the nerve fibers in the optic nerves. The optic nerve from each eye passes backward through the optic foramen, and shortly after leaving the orbit the two nerves come together, and the fibers from the inner portion of each nerve cross. This is called the optic chiasm, and is really an incomplete crossing of fibers, as the outer fibers do not cross. (See Fig. 233.)

(2) *Change in the size of pupil.*—On looking at a near object in a bright light the pupil contracts in order to direct the entering rays to the central parts of the lens, *i.e.*, the part where the convexity and the consequent refractive power are greatest; and to the fovea centralis. In a dim light the pupil is dilated, causing a diffusion of the rays on the peripheral parts of the retina where there is sensitizing purple. The contraction of the pupil is brought about by the stimulation of the circular muscle of the iris by the oculomotor nerve; in a dim light the stimulation is lessened and it dilates. In excitement, fear, etc., its dilatation is due to stimulation of

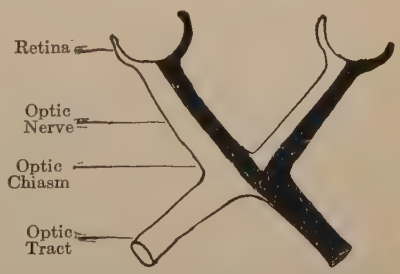


FIG. 233.—DIAGRAM OF OPTIC CHIASM.

sympathetic nerve fibers that arrive by way of the ophthalmic branch of the trigeminal nerve.

(3) *Accommodation.*—Accommodation is the ability of the eye to adjust itself so that it can see objects at varying distances. The theory most generally accepted is that the ciliary muscle is the active agent in accommodation. When the eye is at rest or fixed upon distant objects the suspensory ligament exerts a tension upon the lens which keeps it flattened, particularly the anterior surface to which it is attached. When the eye becomes fixed on near objects, as in reading, sewing, etc., the ciliary muscle contracts and draws forward the choroid coat, which in turn releases the tension of the suspensory ligament upon the lens, and allows the anterior surface to become more convex. The accommodation for near objects is an active condition and is always more or less fatiguing. On the contrary, the accommodation for distant objects is a passive condition, in consequence of which the eye rests for an indefinite time upon remote objects without fatigue.

(4) *Refraction.*—Rays of light entering the pupil are refracted or bent so that they come to a focus on the retina. It occurs because the density of the refractory apparatus is greater than that of air.

Inversion of images.—Due to refraction, light rays as they enter the eye cross each other and cause the image of external objects on the retina to be *inverted*. The question then arises, "Why is it that objects do not appear to us to be upside down?" This question is easily answered if we remember that our actual visual sensations take place in the brain, and that the projection of these sensations to the exterior is a secondary act that has been learned from experience.

Abnormal conditions that interfere with refraction.—The conditions that affect accommodation are: (1) hypermetropia, (2) myopia, (3) presbyopia, and (4) astigmatism.

Hypermetropia.—Hypermetropia or far-sightedness is a condition in which rays of light from near objects do not converge soon enough and are brought to a focus behind the retina. This is usually caused by a flattened condition of the lens or cornea, or an eyeball that is too shallow, and convex lenses[15] are used to concentrate and focus the rays more quickly.

Myopia.—Myopia or near-sightedness is a condition in which rays of light converge too soon, and are brought to a focus before

[15] See page 535.

reaching the retina. This is the opposite of hypermetropia and is caused by a cornea or lens that is too convex, or an eyeball of too great depth. To remedy this condition concave lenses are worn to disperse the rays and prevent their being focussed too soon.

Presbyopia.—Presbyopia is a defective condition of accommodation in which distant objects are seen distinctly, but near objects are indistinct. This is a physiological process which affects every eye sooner or later, and is not due to disease. It is said to be caused by a loss of the elasticity of the lens.

Astigmatism. — Astigmatism is the condition in which the curvature of the cornea or lens is defective. An excess of curvature in the long axis of the cornea, as compared with that of its horizontal axis, is the more common defect. Glasses with curvatures the opposite of those of the eyes are used to correct this defect.

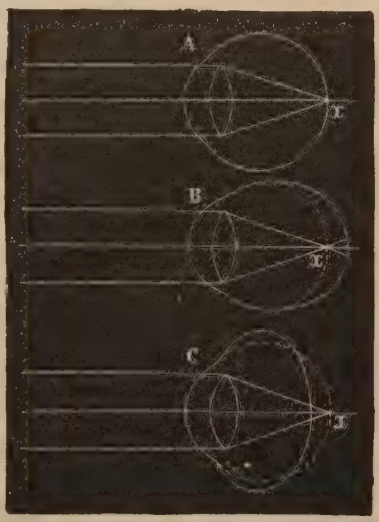


FIG. 234.—DIAGRAM ILLUSTRATING RAYS OF LIGHT CONVERGING IN (A) A NORMAL EYE, (B) A MYOPIC EYE, AND (C) A HYPERMETROPIC EYE.

SUMMARY

Sensory unit
- Peripheral end-organ or receptor.
- Connecting neurons for conduction of nerve impulses.
- A center in the nervous system for interpretation or linkage with motor nerves.
- **Function**—Enable us to derive information about ourselves, one another, and the world in which we live.

Sensation
- The conscious result of the stimulation of receptors.
- Interpreted in the brain.
- **Variety of Classification**
  - Old classification
    - Special, sight, hearing, touch, taste, smell.
    - Common—all other sensations.
  - Based on introspective psychology
    - External or those in which the sensations are projected to the exterior of the body, *i.e.*, sight, smell, temperature, etc.
    - Internal or those in which the sensations are projected to the interior of body, *i.e.*, hunger, thirst, muscle sense, etc.

Sensation

- **Variety of Classification**
  - Based on location of stimuli
    - Extero-ceptors receive stimuli external to the body.
    - Proprio-ceptors receive stimuli within the body.
    - Intero-ceptors receive stimuli from the alimentary canal.
  - Based upon the kind of stimuli
    - Chemo-receptors stimulated by definite substances, *e.g.*, taste, smell, etc.
    - Mechanico - receptors stimulated by mechanical pressure or vibratory impacts, *e.g.*, sound, touch, etc.
    - Radio-receptors stimulated by the effects of radiant energy, *e.g.*, light, heat, cold, etc.

Cutaneous Sensations

- Surface of skin is a mosaic of sensory spots which coincide with location of special end-organs for pressure, cold, heat, or pain.
- **Classification**
  - Epicritic
    1. Fibers for light pressure.
    2. Fibers for small difference of temperature, *i.e.*, between 78.8° and 98.6° F. (26° and 37° C.).
  - Protopathic
    1. Fibers for pain.
    2. Fibers for heat above 98.6° F. (37° C.).

    Fibers for cold below 78.8° F. 26° C.).

    Sensibility low, localization poor.

Pain

- Excessive stimulation of any of the sense organs causes unpleasant sensations.
- Actual pain caused by stimulation of pain receptors.
- Over-distension of hollow organs, or inflammatory conditions will cause pain.
- Pain and other receptors stimulated simultaneously, sensation modified, *i.e.*, burning pain.
- **Function**—Serves as danger signal.
- Referred Pain
  - Pain arising in viscera and referred to skin area supplied with sensory fibers from the same spinal segment that supplies organ in question.

Muscle Sense

1. Sensory end-organs in the muscles, *i.e.*, muscle spindles.
2. Sensory end-organs situated in tendons, *i.e.*, tendon spindles or tendon organs of Golgi.
3. Afferent fibers carry impulses to centers in brain.
4. Efferent fibers carry impulses from brain to muscle.

Hunger

- Normal gastric hunger due to contractions of empty stomach, acting on nerves distributed to mucous membrane.
- Hunger contractions may be frequent and severe, even when food is taken regularly, as in diabetes.

Appetite

- Aroused in part through sensory nerves of taste and smell, associated with previous experience.
- Thought of food associated with appetite induces flow of saliva and gastric fluid.

Thirst

- Normal thirst sensations presumably due to stimulation of sensory nerves of pharynx.
- Prolonged deprivation of water probably affects sensory nerves in many tissues, and interferes with metabolism of nervous system

Nausea
- Due to stimulation from the stomach.
- Due to substances in the blood.
- Due to impulses from organs of
  - sight.
  - taste.
  - smell.

Taste
- Sensory apparatus
  1. Taste buds are end-organs.
  2. Nerve fibers of trigeminal, facial, and glossopharyngeal nerves.
  3. Center in brain.
- Solution of savory substances must come in contact with taste buds.
- Taste buds are distributed over
  - Surface of tongue.
  - Soft palate and fauces.
  - Tonsils and pharynx.

Tongue
- Freely movable muscular organ.
- Attached to hyoid bone, epiglottis, and pillars of the fauces.
- Surface covered by papillæ containing capillaries and nerves
  - Vallate.
  - Fungiform.
  - Filiform.
  - Simple.
- **Nerves**
  - Sensory
    - Lingual, branch of trigeminal.
    - Chorda tympani, branch of the facial.
    - Glossopharyngeal.
  - Motor—Hypoglossal.
- **Sense of** (1. Taste, 2. Temperature, 3. Pressure, 4. Pain) Are all well developed.

Classification of Taste Sensations
- **Four primary sensations**
  - Salty, bitter.
  - Acid, sweet.
- **All others are**
  - Combinations of primary sensations.
  - Combinations of one or more plus odor.

Smell
- Sensory apparatus
  - Olfactory nerve-endings.
  - Olfactory nerve fibers.
  - Center in brain—olfactory bulb.
- Odors
  - Minute particles of solid matter or gases
    - Must be capable of solution in mucus.
  - Classify
    - Pure odors
      - Ethereal, aromatic, fragrant, ambrosial, garlic, burning, goat, repulsive, fetid.
    - Odors mixed with sensations.
    - Odors mixed or confused with taste.
- Olfactory nerve-endings found in lining of upper part of nose (smell).
- Branches of trigeminal nerve found in lining of lower part of nose (pressure).

Hearing
- Auditory apparatus
  - External ear.
  - Middle ear.
  - Internal ear.
  - Acoustic or auditory nerve.
  - Center in brain.
- Air waves enter meatus or external auditory canal and cause vibrations of tympanic-membrane. The vibrations are conveyed to nerve-endings of organ of Corti, and thence by the auditory nerve to the brain.

- **EAR**
  - **External Ear**
    - Auricle or pinna
      - **Structure**—Cartilaginous framework, some fatty and muscular tissue, covered with skin.
      - **Function**—Collects sound waves.
    - Meatus or auditory canal
      - 1 in. long, partly cartilage, partly bone.
      - Closed internally by the tympanic membrane.
      - Hairs directed outward.
      - Ceruminous glands secrete a yellow, pasty substance.
  - **Middle Ear**
    - An irregular cavity in the temporal bone.
    - Five or six drops of water will fill it.
    - Bones
      - Malleus (hammer).
      - Incus (anvil).
      - Stapes (stirrup).
    - Five Openings
      - Opening between it and auditory canal, covered by tympanic membrane.
      - Fenestra vestibuli at end of scala vestibuli. — Connect with internal ear.
      - Fenestra cochleæ at end of scala tympani. — Connect with internal ear.
      - Opening into mastoid antrum and mastoid cells.
      - Eustachian tube—connects with the pharynx; ventilates cavity.
  - **Internal Ear**
    - Bony Labyrinth
      - Vestibule behind the cochlea, in front of the semicircular canals. — Vestibular branch of auditory nerve distributed to vestibule and semicircular canals.
      - Semicircular canals
        - Three in number. — Vestibular branch of auditory nerve distributed to vestibule and semicircular canals.
        - Open into vestibule. — Vestibular branch of auditory nerve distributed to vestibule and semicircular canals.
      - Cochlea
        - A spiral tube.
        - 2¾ turns around modiolus.
        - Fenestra cochleæ.
        - Cochlear branch of the auditory nerve.
      - Surrounded by perilymph.
      - Contains endolymph.
    - Membranous Labyrinth
      - Lines the vestibule
        - Saccule.
        - Utricle.
      - Lines the semicircular canals.
      - Lines the Cochlea
        - Lamina of projecting bone and basilar membrane separates scala vestibuli and the scala tympani. Supports organ of Corti.
    - Acoustic Nerve
      - Cochlear arises from bipolar cells in modiolus
        - Peripheral fibers from each cell terminate in and around the cells of the organ of Corti.
        - Central fibers pass through internal auditory meatus to floor of fourth ventricle.
      - Vestibular arises from nucleus of bipolar cells in internal auditory meatus.
        - Peripheral fibers terminate in hair cells of saccule, utricle and ampulla of the semicircular canals.
        - Central fibers join fibers from the cochlear, extend with them to fourth ventricle.

EAR

- **Internal Ear**
  - **Acoustic Nerve**
    - Nerve fibers that pass from ear to auditory centers not continuous strands—instead there are several relays of ganglia. In the medulla most of the fibers from each ear cross to opposite side.

Physiology of Hearing

- Sonorous bodies produce air waves.
- Air waves enter external auditory canal, set drum-membrane vibrating, vibrations communicated to ossicles, transmitted to membrane of fenestra vestibuli and perilymph, stimulate nerve-endings in organ of Corti, impulses carried to center of hearing in brain.

Sense of Equilibrium

- Function of the vestibule and semicircular canals.
- Lining membrane supplied with sensory hairs which connect with vestibular nerve.
- Contains several small otoliths which float in the endolymph.
- Flowing of the endolymph stimulates the sensory hairs; this is transmitted to the vestibular nerve, thence to auditory nerve, thence to brain.

Visual Apparatus

- Eye.
- Optic nerve.
- Center in brain.
- Accessory organs
  - Eyebrows.
  - Eyelids.
  - Conjunctiva.
  - Lacrimal apparatus.
  - Muscles.
  - Fascia bulb.

Accessory Organs

- **Eyebrows**
  - Thickened ridges of skin furnished with short, thick hairs.
  - Control to a limited extent amount of light admitted to eye.
- **Eyelids**
  - Folds of connective tissue covered with skin, lined with mucous membrane—conjunctiva, which is also reflected over the eyeball.
  - Provided with lashes.
  - Upper lid raised by levator palpebræ superioris.
  - Both lids closed by sphincter-like muscle, orbicularis oculi.
  - Slit between lids called palpebral fissure.
  - Inner angle of slit called medial commissure (canthus).
  - Outer angle of slit called lateral commissure (canthus).
  - **Function**
    1. Close the eyes.
    2. Protect eyes from bright light and foreign objects.
    3. Spread lubricating secretions over surface of eyeball.
  - Tarsal glands are a row of glands embedded in tarsal cartilage of each lid.
- ***Eyelashes and Sebaceous glands***
  - Margin of each lid contains hair follicles.
  - Tarsal glands embedded in tarsal cartilage of each lid.
  - Secretion lubricates edges, prevents adhesion of lids.

Accessory Organs

- **Conjunctiva** — Mucous membrane, lines eyelids, and is reflected over eyeball. Continuous with mucous membrane of lacrimal ducts and nose.
- **Lacrimal apparatus**
  - Lacrimal gland—in the upper and outer part of the orbit. Secretes tears.
  - Lacrimal ducts begin at punctæ and open into lacrimal sac.
  - Lacrimal sac expansion of upper end of naso-lacrimal duct. Center of sac is lacrimal caruncle.
  - Naso-lacrimal canal—extends from lacrimal sac to nose.
  - Tears
    - Secretion constant.
    - Dilute solution of various salts in water, also mucin.
    - Function
      - Keep surface of eyes moist.
      - Help to remove foreign bodies, microörganisms, dust, etc.
      - Carried off by nasal duct.
- **Muscles**
  - **Extrinsic**
    - Superior rectus.
    - Inferior rectus.
    - Internal rectus.
    - External rectus.
    - Superior oblique.
    - Inferior oblique.
  - **Intrinsic**
    - Ciliary muscle — Determines the position of the lens.
    - Muscles of iris
      - Contractor of pupil.
      - Dilator of pupil.

Nerves of Eye

1. Optic nerve concerned with vision only.
2. Oculomotor controls
   - Internal rectus muscle.
   - Superior rectus muscle.
   - Inferior rectus muscle.
   - Inferior oblique muscle.
   - The ciliary muscle.
   - The circular muscle.
3. Trochlear controls the superior oblique muscle.
4. Abducent controls the external rectus muscle.
5. Ophthalmic supplies general sensation, such as pressure, muscle sense, and pain.

Orbit

- Bony cavity formed by seven bones
  - Frontal.
  - Malar.
  - Maxilla.
  - Palatine.
  - Ethmoid.
  - Sphenoid.
  - Lacrimal.
- Contains eyeballs, muscles, nerves, vessels, lacrimal glands, fat, fascia bulb and fascia holding structures in place.
- Lined by fibrous tissue.
- Pad of fat—supports eyeball.
- Fascia bulb envelopes eyeball from optic nerve to ciliary region.
- Shaped like funnel
  - Large end directed outward and forward.
  - Small end directed backward and inward.
- **Optic foramen**—opening for passage of optic nerve and ophthalmic artery.
- **Sphenoidal fissure**—opening for passage of ophthalmic vein and oculomotor, trochlear, and abducent nerves.

Eyeball

Spherical in shape, but it projects anteriorly.

Tunics

1. Fibrous—sclera and cornea.
2. Vascular—choroid, ciliary body and iris.
3. Visual—retina.

Media

1. Aqueous.
2. Crystalline lens and capsule.
3. Vitreous.

Protective Tunics

Sclera

Tough, fibrous, opaque.
Covers dorsal 5/6 of eyeball.
Brown in color internally.

Cornea

Fibrous, transparent—covers ventral 1/6 of eyeball.
Well supplied with nerves.

Vascular Tunics

Choroid

Vascular coat, lines the sclera.
Composed of dense capillary network and stroma of cells, some of which are pigmented.

Ciliary Body

Terminates in front by the ciliary processes.
Ciliary processes 70 to 80 parallel folds of the choroid, rising gradually from behind and forming a plaited zone between the choroid and iris.
Support ciliary muscle—action of this muscle determines the position of the lens.

Iris

A circular colored disc suspended in front of lens and behind cornea. Central perforation—pupil.
Pupil contracted by circular or sphincter muscle.
Pupil dilated by radial or dilator muscle.
Composed of connective tissue, containing numerous blood-vessels and nerves. May contain pigment cells.
Hangs free except for attachment at circumference to the ciliary processes and choroid.
Function—Regulates size of pupil and thereby amount of light entering eye.

Visual Tunic or Retina

Visual layer—contains elements essential for reception of rays of light. Situated between the choroid coat and hyaloid membrane of the vitreous humor.
Has three sets of neurones so arranged that seven layers are formed. These are held in place by neuroglia, and two membranes. Counting from the hyaloid membrane outward:
Membrana limitans interna.
1. Layer of nerve fibers.
2. Cell bodies of third neurones.
3. Area of synapses of second and third neurones.
4. Cell bodies of second neurones.
5. Area of synapses between first and second neurones.
6. Cell bodies of first neurones.
Membrana limitans externa, marking internal limit of rods and cones.
7. Rods and cones of first neurones.

Blind Spot

Entrance of optic nerve.
There are no rods and cones.
Totally insensitive to light.

Macula Lutea

1/12 in. outside the blind spot.
Central pit—fovea centralis—is the center of direct vision.

Refractive Apparatus

- **Aqueous**
  - Aqueous chamber is between cornea in front, and lens, suspensory ligament, and ciliary body behind. Aqueous humor is a watery solution containing minute amounts of chlorid of sodium.
- **Crystalline lens**
  - Fibrous body enclosed in an elastic capsule.
  - Double convex in shape. Situated behind the pupil.
  - Held in position by counterbalancing of the aqueous humor and vitreous body and the suspensory ligament.
- **Vitreous**
  - Semi-fluid, albuminous tissue enclosed in hyaloid membrane.
  - Fills the posterior four-fifths of the globe of the eyeball, distends the sclera and supports the retina.

Perception of Light and Color

- Ether penetrates all space.
- Waves started by the motion of molecules of hot bodies cause vibrations in ether.
- Waves vary in length
  - Electric waves—may be miles long.
  - Light waves—between .0004 to .0008 mm. in length.
  - Chemical waves—are shorter than light waves.

Refraction—Bending or deviation in the course of rays of light, in passing obliquely from one transparent medium into another of different density.

Vision

- Visible objects reflect light waves which fall upon them.
- These reflected rays are brought to focus on receptors (rods and cones) of the retina, transmitted to the optic nerve and thence to centers of vision in occipital lobe of cerebrum, from here to association areas.
- Various theories are suggested to account for vision.

Processes Necessary for Binocular Vision

1. Convergence or turning the eyes inward in order to place the image on both retinas in about the same way.
2. Change in the size of the pupil—contracts in a bright light—dilates in a dim light.
3. Accommodation—Ability of the eye to adjust itself so that it can see objects at varying distances.
4. Refraction—bending of light rays entering the pupil so they come to a focus on the retina.

Conditions that Interfere with Refraction

- **Hypermetropia**
  - Far-sightedness.
  - Cause—Rays of light do not converge soon enough.
- **Myopia**
  - Near-sightedness.
  - Cause—Rays of light converge too soon.
- **Presbyopia**
  - Defective condition of accommodation in which distant objects are seen distinctly, but near objects are indistinct.
- **Astigmatism**
  - Condition in which the curvature of the cornea or lens is defective.

CHAPTER XXIII

REPRODUCTION: MALE ORGANS OF GENERATION; FEMALE ORGANS OF GENERATION

Thus far we have been concerned with the processes of life as we find them in the adult human being. From the time of birth to maturity the result of these life processes, if normal and uninterrupted, is a constant gain. In other words, the anabolic processes are in the ascendancy and the individual gains in weight and stature. Then follows a period during which the anabolic and catabolic changes balance so nicely that in the language of the day the individual is said to be "holding his own." Sooner or later the balance is upset, the catabolic changes gain the upper hand, and a period of retrogression sets in which continues until death supervenes. Since death results in the extinction of the individual all human and animal life would cease if it were not for the process of reproduction, by means of which new life is brought into existence. These new individuals develop and eventually take the place of those who pass on. In turn they reproduce, and the cycle of life is found to be a continuous circle, rather than a straight line. The purpose of this chapter is to present the process of reproduction and the organs concerned with this function.

Sexual reproduction.—This term is applied to the type of reproduction which results from the fusion of two cells known as gametes or sex cells, one of which is produced by the male, and one by the female organism. The female gamete is called the ovum (plural, *ova*). In appearance and structure it differs little from the ordinary cell, but distinctive names have been given its several parts. It is globular, about 1/125 of an inch (0.2 mm.) in diameter, and consists of a minute mass of protoplasm surrounded by a clear elastic membrane known as the zona radiata, or zona pellucida. The cytoplasm contains: (1) a nucleus or germinal vesicle, and (2) a yolk which serves as food for the early development of the embryo. The male gamete is called the spermatozoön (plural, *spermatozoa*). It is smaller than the ovum, being only 1/500 of an inch (0.05 mm.) in length, and is shaped somewhat like a tadpole. It consists of an elliptical

head, a rod-shaped middle piece, and a tail that gradually tapers. There is an active vibratory motion of the tail which allows it quite free motion in the seminal fluid. The head contains a mass of chromatin and is generally regarded as the nucleus of the cell. This chromatin material is formed into rods called chromosomes, the number of which is constant for each species of animal.

Maturation of the gametes.—The number of chromosomes in the human gametes is 48 which, during the process of maturation,[1] become reduced to 24. The matured spermatozoa are thought to be of two kinds half of them containing an X chromosome, and half of them containing a Y chromosome. The matured ova are of one kind: each contain an X chromosome. Maturation takes place either before, during, or after fertilization, but always before the fusion of the sperm and egg nuclei. If it were not for this process each fertilized ovum would contain double the number of chromosomes. As soon as the head of one spermatozoön enters the ovum, the tail disappears, and a tough envelope, the vitelline membrane, develops around the ovum and prevents the entrance of other spermatozoa. The male and female nuclei approach each other and fuse into one, which is known as the cleavage or segmentation nucleus. Following this, mitotic cell division proceeds as described in Chapter II. It is thought (1) that the chromosomes of the nuclei are the physical representatives of the potential characteristics of the parents, and (2) that the cytoplasm of the ovum transmits the characteristics common to the species. Some investigators are of the opinion that the X and Y chromosome are the chief factor in sex determination, *i.e.*, an ovum containing an X chromosome which becomes impregnated with a spermatozoön containing an X chromosome will develop into a female, and one that is fertilized by a spermatoözon that contains a Y chromosome will develop into a male. Other investigators think that certain other conditions of maturation, fertilization and early development are also of importance.

Fertilization.—This term is applied to the fusion of the nuclei of the ovum and sperm cell. Due to this process the normal number of chromosomes characteristic of the species is restored. If the chromosomes are the "physical bearers of inheritance" potentialities, one-half the inherited traits are due to the sperm cell and one-half to the ovum.

[1] For description of maturation see page 19.

Heredity.—This term is applied to the transmission of the potential characteristics of parents to their children. Since each individual begins life as a single cell (zygote) formed by the fusion of the gametes (which are the only link between successive generations), it is obvious that the individual does not inherit its parents' characteristics, but rather the potentialities of those characteristics. In different environments the development of these potentialities may result in quite different characters. Inherited diseases are those which are due to some characteristic of either of the sex cells, and usually appear in successive generations. Examples of such diseases are epilepsy, insanity, hemophilia, color-blindness, and deafmutism, provided the individual's forebears have been so afflicted. If, for instance, insanity or epilepsy is the result of accident or disease occurring before or after birth, then the condition is not inherited. Conditions resulting from injury or disease before birth are spoken of as congenital.

Puberty and adolescence.—As the individual develops, the elements of the reproductive organs are among the first to be differentiated. In fact, many authorities consider them to be differentiated in the zygote. But they do not attain functional maturity until the time of puberty. At the time of puberty the boy begins to develop into a man, and the girl begins to develop into a woman. In temperate climates the age at which boys usually attain puberty is about fifteen years; in girls about a year younger, at fourteen. In southern countries it is somewhat earlier, and in arctic regions, a year or two later. However, no fixed rule can be given, as the time of arrival at puberty varies with every individual, depending on race, temperament, hygiene, and general surroundings.

The essential features of puberty are the production of mature spermatozoa in the male, and the production of mature ova in the female. At birth the male organs (testes) contain thousands of immature spermatocytes, and the female organs (ovaries) contain thousands of immature ova, but these do not mature until the onset of puberty. Puberty is also marked by the gradual appearance of the secondary sex characteristics. In the male this development is thought to depend on an internal secretion produced in the testes. The ovaries of the female produce two internal secretions. One of these is secreted by the cells of the corpus luteum,[2] and the other by the interstitial cells in the sub-

[2] See page 506.

stance of the organ. The development of the secondary sex characteristics in the female depends upon the latter. In the boy the "Adam's apple" develops, producing a marked change in the voice, the external genitals grow somewhat rapidly, hair grows on the face, pubes, axillæ, and other parts of the body, and seminal fluid begins to be secreted. At the same time sexual desires unknown before are experienced

The girl undergoes a gradual change in figure, the hips broaden, the breasts develop, and hair grows on the pubes and axillæ. It is at this time that menstruation begins, but this function is related to the secretion of the corpus luteum and will be described later. In both sexes body growth becomes specially increased at this time, and there is a rapid but varying degree of mental change. These changes are not accomplished at once, but extend over considerable time. The years during which they are taking place are known as the period of adolescence.

MALE ORGANS OF GENERATION

These are:—(1) Two testes or testicles which produce the spermatozoa, and the internal secretion, (2) two vasa deferentia[3] (3) two seminal vesicles, (4) two ejaculatory ducts, (5) two spermatic cords, (6) one scrotum, (7) one penis and urethra, (8) one prostate gland, (9) two Cowper's glands (bulbo-urethral).

Testes.—The testes are two glandular organs which are suspended from the inguinal region by the spermatic cords, and are surrounded and supported by the scrotum. Each gland weighs 10.5 to 14 gms. and consists of two portions: (1) the testicles proper, and (2) the epididymis.

(1) The *testicle proper* is ovoid in shape and covered exteriorly by fibrous tissue which sends incomplete partitions into the central portion of the gland, dividing it into communicating cavities. In these cavities are winding tubules which are surrounded by blood-vessels and held together by interstitial tissue. These tubules inosculate in a sort of mesh (rete testis) and finally all unite in the epididymis.

(2) The *epididymis* is a long, narrow body, which lies along the upper posterior portion of the testicle and consists of a tortuous tubule, which is lined with mucous membrane, and contains some muscular tissue in its walls. If unravelled it is found to be about twenty feet (5 meters) long. It connects the testicle proper with the vas deferens.

[3] Singular Vas deferens.

Function.—The function of the testes is the production of spermatozoa, and an internal secretion which influences the development of the secondary sex characteristics of the male. The reason for this belief is that if the testes are removed before puberty, the boy remains undeveloped, the enlargement of the larynx does not occur, there is no growth of hair on the face, and the features are infantile. The thymus, pituitary and cortex of the adrenals are increased, but the growth of the thyroid is diminished, and mental development tends to be retarded.

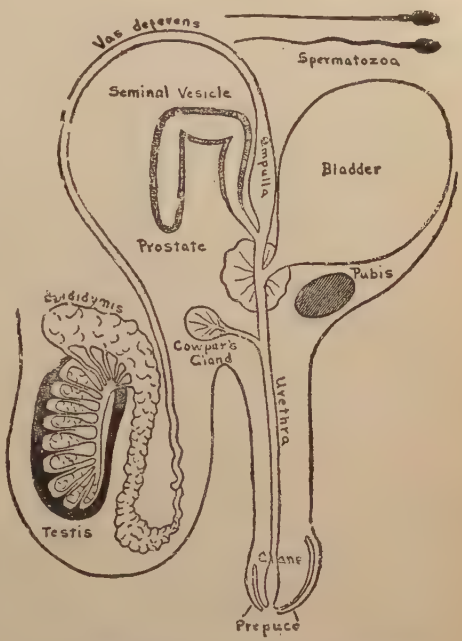


FIG. 235.—MALE SEXUAL APPARATUS. (Hall.)

Descent of the testes.—In early fetal life the testes are abdominal organs lying in front of and below the kidneys. During the process of growth they are drawn downward through the inguinal canal and shortly before birth are normally found in the scrotum. Sometimes, particularly in premature infants, a testis is found in the inguinal canal or even in the abdominal cavity; as a rule it soon descends and occupies its proper position; but occasionally it does not descend and an operation is necessary.

Vas deferens (ductus deferens or seminal duct).—Each duct is a continuation of the epididymis, and is the excretory duct of the testicle. After a very devious course it reaches the prostate gland, which lies in front of the neck of the bladder. Here each duct ends by joining the duct from the corresponding seminal vesicle to form one of the ejaculatory ducts. Each consists of three coats an external areolar, a middle muscular, and an internal mucous coat.

The seminal vesicles.—The seminal vesicles are two sac-like organs which are placed on the outer side of each vas deferens,

between the bladder and the rectum. They are pyramidal in form, with the broad ends directed backward and widely separated. The anterior portions converge, become narrowed, and unite on either side with the corresponding vas deferens to form the ejaculatory duct.

Function.—The seminal vesicles serve as reservoirs for the semen, to which they add a secretion of their own.

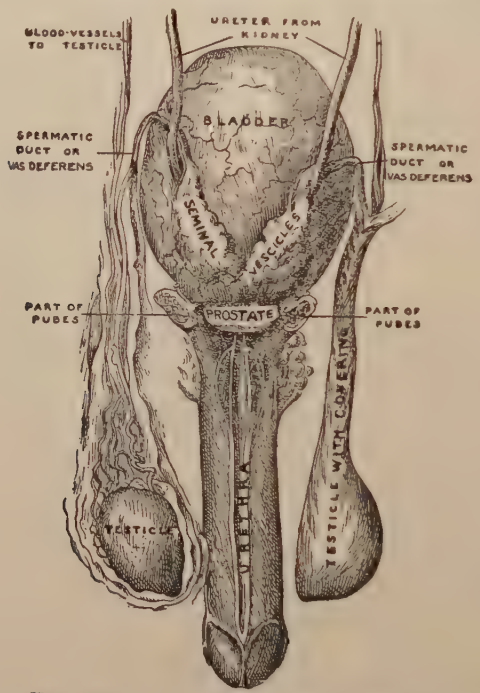


FIG. 236.—MALE GENERATIVE ORGANS.
Courtesy of William Wood & Co., and John Bale Sons & Danielson, Ltd.

The ejaculatory ducts.—The ejaculatory ducts are two in number, one right and the other left. They are formed by the union of the seminal vesicle with the vas deferens and descend, one on each side, and passing between the lobes of the prostate gland, finally reach the urethra into which they open and discharge their contents. Each has an external areolar, middle muscular, and internal mucous coat.

The spermatic cords.—Each cord consists of a seminal duct, an artery, veins, lymphatics, nerves, and connecting areolar tissue covered with fascia that is continuous with that covering the testes. These structures come together and form a cord just

above the internal abdominal ring, through which the cord passes, and descends into the scrotum where it connects with the posterior surface of the testes.

The scrotum.—The scrotum is a pouch consisting of (1) a layer of thin relatively dark skin, disposed in folds or rugæ and in the adult covered with short hairs; and (2) the dartos tissue made up of elastic tissue, plain muscular tissue, and numerous blood-vessels. The dartos sends in a fold of tissue which serves as a partition dividing the interior of the scrotum into two chambers, and separating the testes. The tissues of the scrotum are continuous with those of the groin and the perineum. The scrotum contains and supports the testes, and the lower part of the spermatic cords.

The penis.—The penis is an organ attached above to the symphysis pubis and suspended in front of the scrotum. It is composed of three cylindrical masses of cavernous tissue bound to-

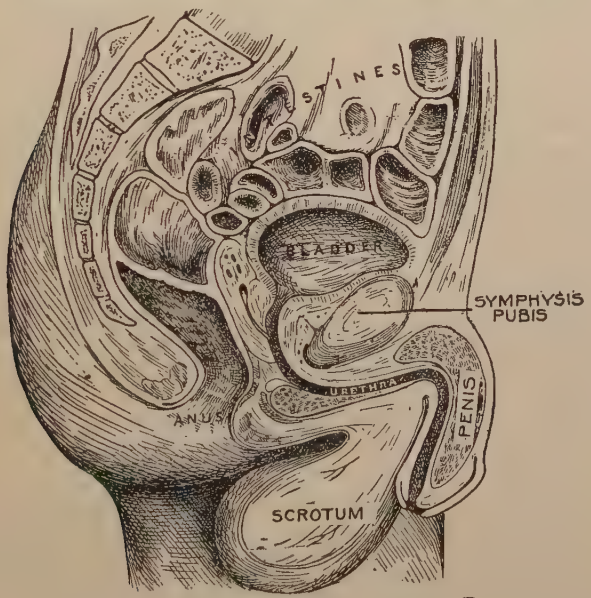


FIG. 237.—MEDIAN SECTION OF MALE PELVIS,
Courtesy of Wm. Wood and Co., and John Bale Sons and Danielson, Ltd.

gether by fibrous tissue and covered with skin. Two of the masses are lateral and are known as the corpora cavernosa penis; the third is median and is termed the corpus cavernosum urethræ because it contains the urethra. The term cavernous tissue is used because of the relatively large size of the venous spaces

which exist in this tissue. It is also described as erectile tissue because the venous spaces may become distended with blood, thus enlarging the tissue and increasing its turgidity. The skin covering the penis is continuous with that covering the scrotum, the perineum, and the pubes. At the end of the penis there is a slight enlargement known as the glans penis, in which the urethral orifice is situated. In the region of the glans, the loose integument of the penis becomes folded inward, and then backward upon itself forming the prepuce or foreskin. Sometimes this foreskin covers the glans too tightly. This condition is known as *phimosis*.

The urethra extends from the bladder through the corpus cavernosum urethræ to the end of the penis. The length is usually given as seven to eight inches (17.5 to 20 cm.), a large part of which lies inside the pelvis. It is lined with mucous membrane and furnished with numerous muscular fibers.

The prostate.—The prostate gland is situated in front of the neck of the bladder and around the commencement of the urethra. It resembles a chestnut in form and consists of a dense fibrous capsule containing glandular and muscular tissue. The glandular tissue consists of tubules which communicate with the urethra by minute orifices.

Function.—The function of the prostate gland is to secrete the prostatic fluid, which is an essential element of the seminal fluid. It gives motility to the spermatozoa.

Cowper's glands (bulbo-urethral).—These are two small bodies about the size of a pea situated one on each side of the prostate gland. Each one is provided with a duct about 1 inch (2.5 cm.) in length which terminates in a minute orifice in the wall of the urethra. These glands secrete a viscid fluid, which goes to form part of the seminal fluid.

Semen.—The semen is a fluid derived from the various sexual glands in the male. The main elements in this fluid are the spermatozoa; the other constituents are derived from the seminal vesicles, prostate gland, and Cowper's glands.

FEMALE ORGANS OF GENERATION

These are: (1) the two ovaries which produce the ova, and two internal secretions, (2) two uterine (Fallopian) tubes, (3) one uterus, (4) one vagina, (5) the external genitals, (6) two breasts.

Ovaries.—The ovaries are two almond-shaped, glandular bodies, situated one on each side of the uterus, in the posterior

fold of the broad ligament, behind and below the uterine tubes. Each ovary is attached at its inner end to the uterus by a short ligament,—the ligament of the ovary,—and at its outer end to the uterine tube by one of the fringe-like processes of the fimbriated extremity. The ovaries each measure about one and a

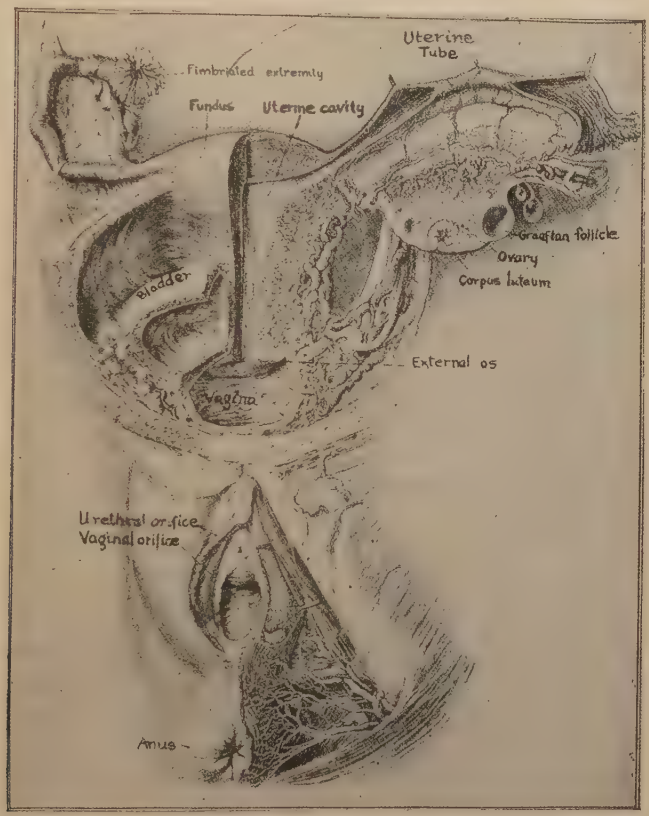


FIG. 238.—FEMALE GENERATIVE TRACT SHOWING BOTH EXTERNAL AND INTERNAL ORGANS. The internal organs are represented as laid out flat, parallel with the external organs. (Reproduced from American FROHSE Life-Size Anatomical Charts. A. J. Nystrom & Company, Chicago, Publishers.)

half inches (4 cm.) in length, three-fourths of an inch (2 cm.) in width, and one-third of an inch (8 mm.) in thickness, and weigh from 2 to 3.5 gms.

Structure.—If the substance of an ovary be minutely examined it is found to consist of: (1) a stroma or bed composed of a loose meshwork of connective tissue containing muscle tissue, blood-vessels, lymphatics, and nerves, (2) Graafian follicles, and (3) a

covering of columnar epithelial cells, called germinal epithelium.

Graafian (vesicular) follicles.—The Graafian follicles are sacs or vesicles which contain the ova and are embedded in the meshes of the stroma.

Each follicle consists of: (1) an outer coat of fibrous tissue that is derived from the stroma, and connected with it by a plexus of blood-vessels, and (2) an inner layer of nucleated cells. With the exception of the smallest follicles each one is filled with fluid, —the liquor folliculi—and suspended in this fluid is an *ovum* surrounded by a mass of cells, called the *discus proligerus.*

At birth the ovaries are said to contain about 70,000 potential ova closely packed in the interior of the organ, but only a small number of these ever develop, as the great majority shrink and disappear. At the time of puberty the ovaries enlarge, become very vascular, and some of the follicles increase in size. As the follicles increase in size they approach the surface and begin to form small protuberances on the outside of the ovary. When fully matured the wall of the ovary and the wall of the follicle burst at the same point, and the contents of the follicle—the fluid, the ovum, and the surrounding cells—escape. This process of development, maturation, and rupture of a follicle is known as ovulation, and continues at regular intervals from puberty to the menopause.

The corpus luteum.—After the rupture of a follicle, and the escape of the ovum, the cavity becomes filled with blood. The remaining parts of the Graafian follicles multiply and rapidly fill the cavity with cells. Due to degenerative changes and the formation of fat this mass of cells becomes yellow, hence the name corpus luteum, which means yellow body. The corpus luteum continues to enlarge for about two weeks after ovulation, then it disintegrates and is absorbed before the next follicle comes to maturity, but if the fertilization of the ovum takes place, the corpus luteum continues to develop until about the third month of pregnancy, and persists until the end of pregnancy.

Function.—The function of the ovaries is to produce, develop and mature the ova, and to discharge them when fully formed. It also furnishes two internal secretions, one formed by the interstitial cells in the body of the ovary, and the second by the corpus luteum. It is believed (1) that the development of the secondary sex characteristics is dependent on the first secretion, and (2) the function of menstruation is dependent on a hormone secreted by the corpus luteum.

The basis for these beliefs is: (1) if the ovaries are removed before puberty or remain undeveloped, the uterus remains small, there is an absence of menstruation, the breasts do not develop, and the growth of hair on the body is greater than is usual in the female. (2) If the ovaries are removed after puberty, the uterus and vagina atrophy, menstruation ceases, and various symptoms due to derangement of the nervous and metabolic processes develop. These symptons are similar to those which occur at the time when menstruation normally ceases, *e.g.*, the menopause. The most typical are (*a*) vasomotor reactions, *i.e.*, changes in the size of the blood-vessels, which increase or diminish the amount of blood sent to the affected part, which is usually the skin of the face and neck. These changes give rise to sensations of alternating heat and cold, sweating, dizziness, muscular pains, headache, and sometimes abnormal mental conditions; (*b*) the amount of carbohydrates that can be oxidized is diminished and obesity is common.

Uterine (Fallopian) tubes.—The uterine tubes or oviducts are two in number, one on each side, and pass from the upper angles of the uterus in a somewhat tortuous course between the folds and along the upper margin of the broad ligament, towards the sides of the pelvis. They are about four inches (10 cm.) long, and at the point of attachment to the uterus are very narrow, but gradually increase in size so that the distal end is larger. The margin of the distal end is surrounded by a number of fringe-like processes called *fimbriæ*. One of these fimbriæ is attached to the ovary. The uterine opening of the tube is minute, and will only admit a fine bristle; the abdominal opening is comparatively much larger.

The uterine tube consists of three coats—(1) the external, or **serous,** coat is derived from the peritoneum, (2) the middle, or **muscular,** coat has two layers: one a layer of longitudinal cells and the other of circular cells; (3) the internal, or **mucous,** coat is arranged in longitudinal folds and covered with ciliated epithelium. It is continuous at the inner end with the mucous lining of the uterus, and at the distal end with the serous lining of the abdominal cavity. This is the only place in the body where a mucous and serous lining are continuous with one another.

Function.—The function of the uterine tubes is to convey the ova from the ovaries to the uterus. Just how the ovum, after its discharge into the abdominal cavity, reaches the uterine tube is not known. It is thought that the movement of the

cilia on the fimbriæ and in the tubes produces a current which draws the ovum into the tube. After the ovum enters the tube it is carried to the uterus by the peristaltic action of the tube and the movement of the cilia. If the ovum does not become fertilized it will be washed out of the uterus by the next menstrual flow. It is considered probable that many of the ova discharged from the ovaries remain in the abdominal cavity, because of failure to reach the tubes. These ova disintegrate, are absorbed, and carried away by the blood. Occasionally such an ovum becomes impregnated and starts to develop in the abdominal cavity, but conditions are not suited for the development of the embryo, and the pregnancy terminates.

The uterus.—The uterus is a hollow, pear-shaped muscular organ. In the virgin state it is situated in the pelvic cavity between the bladder and the rectum. Its length is estimated to be about three inches (7.5 cm.), its width two inches (5 cm.) at the upper part, and its thickness one inch (2.5 cm.). During pregnancy the uterus becomes enormously enlarged, attains the length of a foot (30 cm.) or more, extends into the epigastric region, and measures about eight to ten inches (20 to 25 cm.) in width. After parturition the uterus returns to almost its original size, but is always larger than before pregnancy. After the menopause, the uterus becomes smaller and atrophies.

Divisions.—For purposes of description the uterus is divided into three parts; (1) the *fundus* is the convex part above the entrance of the tubes, (2) the *body* is the part between the fundus and the neck, (3) the *cervix* or neck is the lower constricted part and extends from the body of the uterus into the vagina.

The cavity of the uterus is small because of the great thickness of its walls; that part within the body is triangular in shape (▽), and has three openings, one at each upper angle, communicating with the uterine tubes, and one, the internal orifice, opening into the cavity of the cervix below. The cavity of the cervix, which is, of course, continuous with the cavity in the body, is constricted above, where it opens into the body by means of the internal orifice (internal os), and below, where it opens into the vagina by means of the external orifice (external os). Between these two openings the canal of the cervix is somewhat enlarged.

Structure.—The walls of the uterus are thick and consist of three coats:—

(1) An external **serous** coat derived from the peritoneum. It covers all of the fundus, and the posterior surface of the cervix, but not the anterior surface.

(2) A middle **muscular** coat which forms the bulk of the uterine walls. It consists of layers of plain muscular tissue intermixed with blood-vessels, lymphatics, and nerves. The arrangement of the muscles is very complex, as they run circularly, longitudinally, spirally, and cross and interlace in every direction.

(3) An internal **mucous** membrane, which is continuous with that lining the vagina and uterine tubes. It is highly vascular, provided with numerous mucous glands, and is covered with ciliated epithelium, except the cervical canal, where it loses its cilia and gradually changes to stratified squamous epithelium similar to that lining the vagina.

Blood supply of uterus.—The uterus is abundantly supplied with blood-vessels. The blood reaches the uterus by means of the uterine arteries from the hypogastrics, and the ovarian arteries from the aorta. Where the neck joins the body of the uterus, the arteries from both sides are united by a branch vessel called the circumflex artery. If this branch is cut during a surgical operation, or a tear of the neck during parturition extends so far as to sever it, the hemorrhage is very profuse. The arteries are remarkable for their tortuous course and frequent anastomoses. The veins are of large size, and correspond in their behavior to the arteries.

Position of the uterus.—The uterus is not firmly attached or adherent to any part of the skeleton. It is, as it were, suspended in the pelvic cavity by ligaments. A full bladder tilts it backward; a distended rectum, forward. It alters its position, by gravity, or with change of posture. During gestation it rises into the abdominal cavity.

The fundus of the uterus is inclined forward, and the external orifice is directed downward and backward. (See Fig. 239.) *Anteversion* is the condition where the fundus turns too far forward. *Retroversion* is the condition where the fundus inclines backward. A bend may exist where the neck joins the body, if the body is bent forward, it is described as *anteflexion;* if bent backward, *retroflexion.*

Ligaments.—The uterus is suspended by eight ligaments. Six are arranged in pairs.

1. The **broad,** or **lateral ligaments,** two in number, are folds of peritoneum slung over the front and back of the uterus, and

extending laterally to the walls of the pelvis. They are composed of two opposed, serous layers, and between these layers are found the following structures: (*a*) uterine tubes; (*b*) the ovaries and their ligaments; (*c*) the round ligaments; (*d*) blood-vessels and lymphatics; (*e*) nerves; (*f*) some smooth muscle tissue.

The posterior fold covers the back of the uterus, and extends far enough below to also cover the upper one-fifth of the back wall of the vagina, when it turns up and is reflected over the anterior wall of the rectum. Thus the uterus, with and between

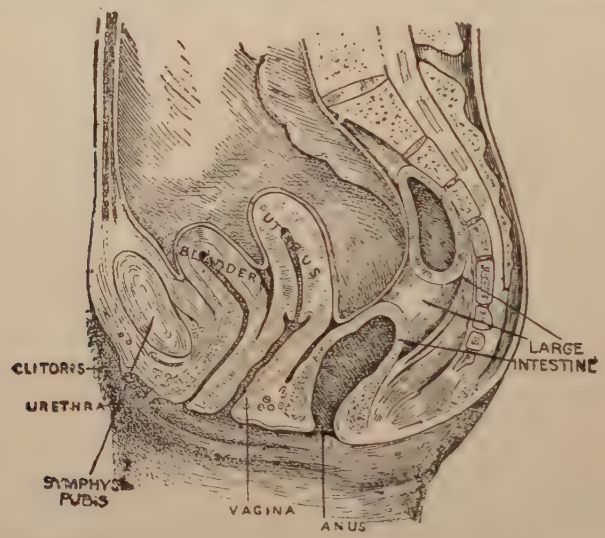


FIG. 239.—MEDIAN SECTION OF FEMALE PELVIS. Courtesy of William Wood and Co. and John Bale Sons and Danielson, Ltd.

its two broad ligaments, forms a transverse partition in the pelvic cavity, the bladder, vagina, and urethra being in the front compartment, and the rectum in the back compartment.

The smooth muscles of the broad ligaments are derived from the superficial muscular layer of the uterus. They pass out between the serous folds and become attached to the pelvic fascia.

2. Between the bladder and uterus the peritoneum forms a shallow pouch called the utero-vesical pouch. This peritoneum, which forms the floor of the pouch, is described as the **anterior ligament** of the uterus.

3. Behind the uterus the peritoneum forms a second and deeper pouch called the recto-vaginal, or cul-de-sac, of Douglas. This peritoneum is described as the **posterior ligament.**

4. The **round ligaments** are two rounded, fibromuscular cords, situated between the folds of the broad ligament. They are about four to five inches (10 to 12 cm.) long, and take their origin from the upper angle of the uterus (on either side), in front and a little below the attachment of the uterine tube. They extend forward and outward, and finally end in the tissues of the labia majora and mons Veneris. The round ligaments are composed of muscles, areolar tissue, blood-vessels, and nerves.

5. The **utero-sacral ligaments** extend between the cervix and sides of the rectum. They serve to connect the cervix and vagina with the sacrum, and are partly serous, partly of smooth muscular tissue.

Function.—The function of the uterus is to receive the ovum from the uterine tubes, and if it becomes fertilized to retain it during its development. Later when the ovum has developed into a mature fetus, it is expelled from the uterus, chiefly by the contractions of the uterine walls.

The vagina.—The vagina is a musculo-membranous canal which encircles the lower portion of the cervix, and extends downward and forward from the uterus to the vulva.

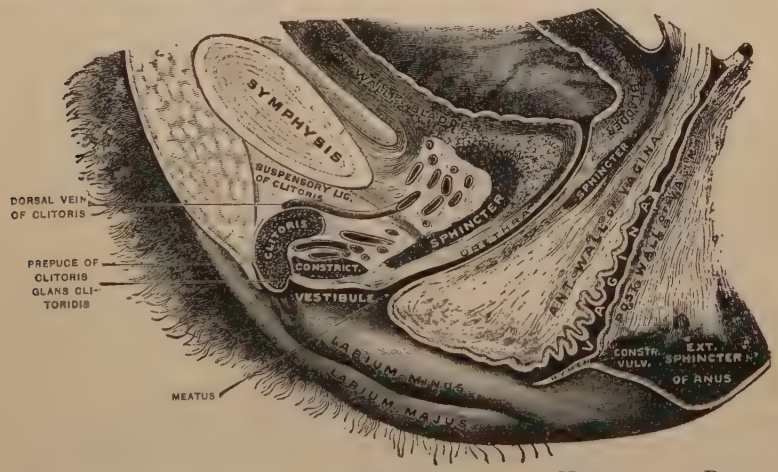


FIG. 240.—SAGITTAL SECTION OF THE VAGINA AND NEIGHBORING PARTS. (Gerrish.)

The posterior wall is about three and three-quarter inches (9 cm.) long, while the anterior wall is only two and one-half to three inches (6 to 7.5 cm.). The front, or anterior wall, is united by connective tissue with the posterior walls of the bladder and urethra, the partition, or septum, between the bladder and vagina

being called the vesico-vaginal, and that between the urethra and vagina the urethro-vaginal, septum.

Structure.—The vagina is made up of three coats: an outer, **fibrous and elastic**; middle, **muscular**; and inner, **mucous,** which in the ordinary contracted state is thrown into folds, its anterior and posterior walls being in contact. The muscular coat increases during pregnancy, and the mucuous coat, because of the transverse folds, or rugæ, allow of dilatation of the canal during labor and birth.

The external genitals.—The external genitals are grouped under the name of vulva or pudendum and include the following:—(1) the mons pubis, (2) the labia majora, (3) the labia minora, (4) the clitoris, (5) the hymen, (6) vestibular glands.

Mons Pubis.—The mons pubis is an eminence situated in front of the pubic bones. It consists of areolar, adipose, and fibrous tissue covered with skin and after puberty with hair.

Labia majora.—The labia majora are two longitudinal folds of skin which are continuous with the mons pubis in front, and extend to within an inch (25 mm.) of the anus behind. This area is called the perineum. Between the folds of the labia there are blood-vessels, nerves, glands of the sebaceous type, adipose, and connective tissue.

Labia minora.—The labia minora are two longitudinal folds of modified epithelium resembling mucous membrane. They are situated between the labia majora. They are joined anteriorly in the hood or prepuce of the clitoris, and extend downward and backward for about one and one-half inches (4 cm.).

The clitoris.—The clitoris a small body situated at the apex of the triangle formed by the junction of the labia minora. It consists of erectile tissue, contains many vessels and nerves, and is almost completely covered by the hood or prepuce.

The hymen.—The hymen is a fold of mucous membrane which surrounds the lower part of the vagina and renders the orifice smaller. It is quite elastic and may remain intact even after child-birth. Occasionally it extends entirely across and closes the orifice altogether. This condition is spoken of as imperforate hymen.

Glands.—In connection with the vulva are found:—

(1) The **vestibular** or **vulvo-vaginal glands** are two round, or oval, glands, situated on either side of the vagina. Their ducts

open into the vestibule one on either side of the vaginal orifice. Their secretion lubricates the vulval canal.

(2) The walls and the floor of the urethra contain numerous **urethral** glands that secrete mucous fluid.

Perineum.—The perineum bounds the external outlet of the pelvis and constitutes the floor of the genital canal. It consists of bands of muscular tissue strengthened and held together with fascia and covered with skin. An important part of the perineum is the triangular portion between the vagina and rectum. It is distensible and stretches to a remarkable extent during labor. Nevertheless it is frequently torn, and when the tear is of any extent, and is not repaired, the vagina and uterus lose the support afforded by it, and various abnormal conditions follow.

PHYSIOLOGY OF THE FEMALE GENERATIVE ORGANS

Functions.—The functions of the female generative organs are: (1) the formation and development of the ovum, (2) the retention and sustenance of the fecundated ovum until it develops into a mature fetus ready to live outside the body, and (3) the expulsion of the fetus.

Puberty.—Puberty is the period at which the sexual organs become matured and functional and the girl develops into a woman. This has been described on page 499.

Ovulation.—Ovulation includes the process of the development and maturation of the follicle and its ovum, and the rupture of the follicle.

The commonly accepted theory is that about or shortly before the age of puberty, the Graafian follicles begin to discharge their ova, and this process continues until the menopause. On an average, one follicle ripens every four weeks.

Menstruation.—Menstruation consists of the periodical discharge of bloody fluid from the uterine cavity. When once established it occurs on the average every twenty-eight days from the time of puberty to the menopause, with the exception of the period of pregnancy and lactation. The average duration is from four to five days and the amount of blood lost may be as much as ten ounces (300 cc.). The menstrual fluid consists of mucin epithelial cells, and blood. The amount of destruction of the mucous membrane varies a good deal, but it usually involves the surface epithelium.

Changes in the generative organs in connection with the menstrual cycle.—Menstruation consists of a cycle occupying

approximately twenty-eight days. At the beginning of the cycle there is a general congestion of the generative organs, including the breasts, accompanied by more or less discomfort and even pain. The mucous membrane of the uterus undergoes the following changes: (1) some days before the process there is marked hypertrophy and congestion of the mucous membrane, (2) during menstruation there is capillary hemorrhage and the epithelium of the mucous membrane may be cast off, (3) during the week following menstruation a new epithelium is formed and the mucous membrane returns to its normal size, (4) a period of rest extends to the next period of congestion.

Causes of menstruation.—At the present time the generally accepted view is that menstruation is dependent upon the ovaries, and that their influence is exerted through the medium of the blood. It is thought that an internal secretion is formed in the ovaries by the cells of the corpus luteum. This secretion is carried to the uterus by the blood and is responsible for the hypertrophy and congestion that precedes menstruation. The fact that operations for the removal of the ovaries are followed by atrophy of the uterus and cessation of menstruation, supports the theory that the ovaries are responsible for menstruation.

The menopause or climacteric.—By menopause or climacteric is meant the physiological cessation of the menstrual flow, and the end of the period during which the Graafian follicles develop in the ovaries, and consequently the end of the child-bearing period. It is marked by atrophy of the breasts, uterus, tubes, and ovaries. The age of menopause varies as does the age of puberty; in general, we may say the earlier the puberty the later the menopause, and *vice versa*. In temperate climates the average period for the arrival of the menopause is at the age of forty-five years.

Mammary glands.—The two mammary glands, or breasts, secrete the milk which is needed for the nourishment of the young infant.

Location.—Each breast covers a nearly circular space in front of the pectoral muscles, extending from the second to the sixth rib, and from the sternum to the border of the arm-pit

Structure—The breasts are convex in shape, are covered externally by skin, and about the center of the convexity a papilla projects, which is called the nipple. The nipple contains the openings of the milk ducts, and is surrounded by a small circular area of pink or dark colored skin, which is called the *areola*. They are compound glands, and are divided by connective tissue parti-

tions into about twenty lobes, each of which possesses its own excretory duct, which as it approaches the top of the breast dilates and forms a small reservoir in which milk can be stored during the period when the gland is active. Each duct opens by a separate orifice upon the surface of the nipple. The lobes are subdivided, and the small lobes, or lobules, are made up of the terminal

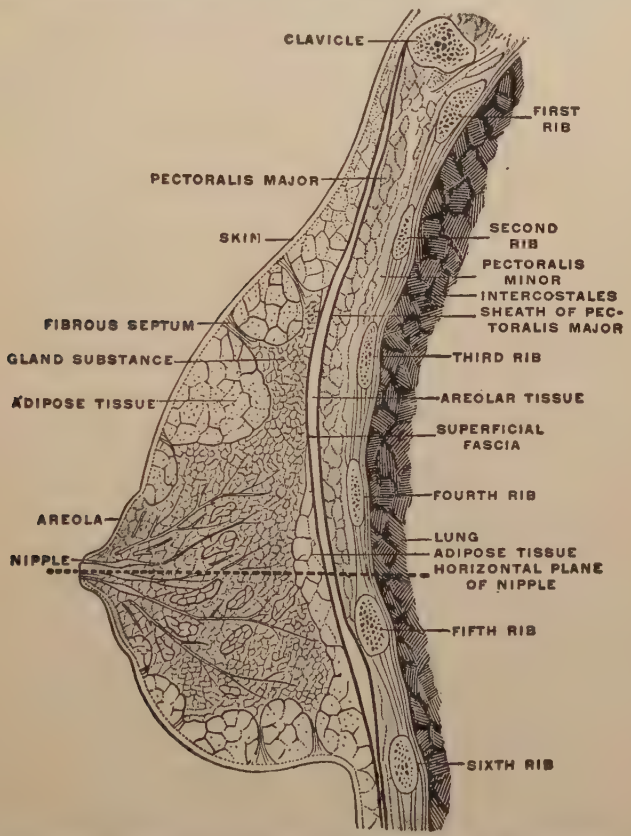


FIG. 241.—RIGHT BREAST IN SAGITTAL SECTION, INNER SURFACE OF OUTER SEGMENT. (Gerrish.)

tubules of the duct, which lie in a mesh of fibrous areolar tissue containing considerable fat.

Blood-vessels and nerves.—The mammary glands are well supplied with blood brought to them by branches of the axillary, internal mammary, and intercostal arteries. The nerves are afferent and vasomotor.

Development of the mammary glands.—The increase in the

size of the mammary glands at the time of puberty is due to an increased development of the connective tissue and fat. The glandular tissue remains undeveloped and does not function unless conception takes place. When conception occurs the glandular tissue undergoes a process of gradual development that produces marked changes. The breasts become larger and harder, the veins on the surface become more noticeable, the areola becomes enlarged and darkened, the nipple becomes more prominent, and toward the end of pregnancy a fluid called colostrum can be squeezed from the orifice of the ducts. After delivery the amount of colostrum increases for a day or two, and then the secretion changes to milk.

The primary development and later functioning of the mammary glands suggest an intimate connection between these glands and the uterus and ovaries. The present theory is that the increase in the size of the breasts at the time of puberty is influenced by the internal secretion from the interstitial cells of the ovaries, for if the ovaries are removed before puberty, the breasts do not develop, or if the ovaries are removed after puberty, the breasts are apt to atrophy. The development of the glandular tissue that follows conception is thought to be due to a hormone, produced by the corpus luteum. If a new pregnancy occurs during the period of lactation, the character of the milk changes, and its secretion is checked. The stimulus which causes the active secretion of milk is thought to result from the emptying of the milk ducts, because of the fact that when a woman does not nurse her infant, the secretion of milk is checked after a preliminary period of turgidity and the breasts return to their usual size. The active secretion of milk is also influenced by the nervous system, and this influence is probably exerted through the vasomotor nerves which control the size of the blood-vessels, and consequently the amount of blood sent to the gland.

The secretion of milk.—The secretory portion of the mammary glands is the milk ducts, and these are lined with secreting cells. Some of the constituents of the milk, *i.e.*, water, salts, and sugar, are secreted by these cells from the blood, but it is thought that the cells themselves disintegrate and form the proteins and fat. The sugar contained in the milk is lactose ($C_{12}H_{22}O_{11}$) and the sugar of the blood is glucose ($C_6H_{12}O_6$) and if the first is derived from the second, it must be by the process of dehydration.

Colostrum and milk.—The secretion of the mammary glands during the first few days of lactation is called colostrum. It is a

thin, yellowish fluid, composed of proteins, fat, sugar, salts, and water, but not in the same proportion as in milk. It also contains numerous cells containing large masses of fat. These are called colostrum corpuscles, and are secreting cells that are not completely broken down.

Human milk is specially adapted to the requirements of the infant and so differs in some respects from that of all other animals. Cow's milk is most frequently substituted for human milk and the relative composition of the two can be seen in the following table:—

	HUMAN (average)	Cow's (average)
Water	88.4%	88.1%
Proteins	1.5%	3.2%
Fat	3.3%	3.9%
Lactose	6.5%	4.9%
Salts	0.3%	0.9%

In substituting cow's milk for human milk the differences that must be taken into consideration are not only the different relative proportions, but also the following: (1) the difference in the proteins; the protein of human milk is one-third caseinogen, and two-thirds lactalbumin, and that of cow's milk is five-sixths caseinogen and one-sixth lactalbumin; (2) the difference in the curds formed in the stomach; human milk curdles in small flocculi, and cow's milk curdles in large heavy curds; and (3) the reaction[4] of human milk is practically neutral pH 7.0 to 7.2; cow's milk is slightly acid pH 6.6 to 6.8 when first drawn, but the acidity increases on standing; (4) human milk is sterile, and cow's milk due to the handling it undergoes contains a large number of microörganisms. Pasteurization destroys the microorganisms usually found in milk, but unless it is done very carefully, it also destroys the vitamins. (5) Human milk contains antitoxins and antibacterial substances that have been formed in the mother's blood, and as it is ingested directly from the breast, its germicidal power is at its height. Cow's milk may also have germicidal value, but this soon deteriorates and usually is lost by the time it is given to the child.

Conception and pregnancy.—The term conception is applied to the union of a spermatozoön with an ovum. Pregnancy implies

[4] For table showing reaction of fluids see Applied Biochemistry by W. Morse, 1925 edition.

a developing embryo within the uterus. When the Graafian follicle ruptures and an ovum escapes into the abdominal cavity, the current produced by the cilia of the tubes is thought to draw it into the tube. Once in the tube the peristaltic action of the tube and the action of the cilia propel it slowly along to the uterus. When the spermatozoa are placed in the vagina at the mouth of the uterus, the vibratory movement of their tails enables them to swim along the lining membrane through the uterus and into the uterine tubes. It is here that the fertilization usually takes place. As previously stated, maturation of the spermatozoön occurs either before or after the head of the sperm has entered the ovum. The fertilized cell is known as a zygote.

Segmentation.—The fertilized cell (zygote) rapidly divides into two, each of these two into other two, and so forth, until we have a number of cells where formerly there was one. At this stage the collection of cells is called the blastoderm. Gradually these cells which constitute the blastoderm become arranged in three layers, the outer called the ectoderm, an inner called the entoderm, and a middle layer called the mesoderm.[5] Later the organs are formed by the folding off of these tissues, and as the embryo grows it takes on the form of the adult.

The passage of the fertilized ovum through the tubes requires about eight days, and during this time many thousands of cells are formed and enclosed in two membranes called the chorion and amnion. The collection of cells surrounded by the membranes is called an *embryo*. After entering the uterus the embryo attaches itself to the mucous membrane, in the upper portion, usually near the opening of the uterine tubes.

Occasionally the ovum does not pass through the tube and what is known as tubal pregnancy ensues. This is a dangerous condition because the tubes are not large enough for the growing embryo. This may result in the rupture of the tube and a serious hemorrhage.

Changes in the uterine lining.—The preparation of the mucous membrane of the uterus for the reception of the impregnated ovum includes changes that are similar to those that precede menstruation. The mucous membrane becomes softer, thicker, and highly congested. In this condition it is known as the *decidua vera*, and the point to which the ovum becomes attached and which later develops into the placenta is called the *decidua basalis*.

Intrauterine growth.—During the period of intrauterine life

[5] See page 20.

growth takes place rapidly. From the union of the ovum, which is $\frac{1}{125}$ inch (0.2 mm.) in diameter, and the spermatozoön, which is much smaller, there is developed in two weeks' time an embryo which is about $\frac{1}{4}$ of an inch (6.25 mm.). At the end of four weeks it is about $\frac{1}{2}$ inch (12.5 mm.) long, and at four months it is called a fetus, because it has the appearance of a human being, with well-developed eyes, fingers and toes separated, and the external genitals sufficiently formed to determine the sex. The usual duration of pregnancy is ten lunar or nine calendar months. At the end of six months the fetus is sufficiently developed to live outside the mother's body, but it is frail and requires a great deal of care.

For further details on the subject of reproduction the student is referred to standard works on physiology and obstetrics.

SUMMARY

Life processes
- Phenomena of activity and growth.
- Early life—anabolic processes in ascendancy, individual gains in weight and stature.
- Middle life—anabolic and catabolic changes balance each other, and individual holds his own.
- Old age—catabolic changes in ascendancy, final result is death

Reproduction
- Means by which new life is brought into existence.
- Sexual type depends upon the union of two cells, one of which is produced by the male and one by the female organism.

Gametes
- Female sex cell—ovum—1/125 in. in diameter. Mass of protoplasm surrounded by membrane, contains (1) nucleus, (2) a yolk which serves as food for the early development of the embryo.
- Male sex cells—spermatozoön—1/500 in. in length, shaped like a tadpole, consists of head, middle piece and tail. Head is nucleus, and contains chromosomes.

Maturation of the Gametes
- Number of chromosomes in human gametes is 48. During process of maturation reduced to 24.
- Matured spermatozoa of two kinds, half contain an X chromosome, and half contain a Y chromosome.
- Matured ova are of one kind, each containing an X chromosome.
- Maturation occurs before the fusion of the sperm and egg cell.

Segmentation Nucleus
- Formed by union of nuclei of male and female gametes.
- Mitotic divisioning follows this union.

Fertilization
- Term applied to fusion of nuclei of ovum and sperm cell.
- Restores normal number of chromosomes, hence one-half contributed by each sex.

Heredity

- Transmission of the potentialities of characteristics from parents to children.
- It is thought (1) chromosomes are special elements that transmit these potentialities, and (2) cytoplasm of ovum transmits characteristics of species.
- Inherited diseases are due to some characteristic of either of the sex cells.

Puberty

- Age at which sex organs become matured and functional.
- Boy begins to develop into man—temperate climate about 15 years of age—essential feature is production of mature spermatozoa.
- Period marked by gradual appearance of secondary sex charteristics—dependent on internal secretion of testes.
- Girl begins to develop into woman—temperate climate about 14 years of age. Essential feature production of mature ova.
- Period marked by gradual appearance of secondary sex characteristics—dependent on internal secretion produced by interstitial cells in substance of ovaries. Function of menstruation starts—dependent on secretion from corpus luteum.

Adolescence—Period during which development included under *puberty* is taking place.

Male Organs of Generation

- 2 Testes or testicles which produce spermatozoa, and an internal secretion.
- 2 Vasa deferentia (ductus deferentia or seminal ducts).
- 2 Seminal vesicles.
- 2 Ejaculatory ducts.
- 2 Spermatic cords.
- 1 Scrotum.
- 1 Penis and urethra.
- 1 Prostate gland.
- 2 Cowper's glands (bulbo-urethral).

Testes

- Two glandular organs which produce the spermatozoa.
- **Structure**
  - **Testicle proper**—ovoid body covered by fibrous tissue. Central portion consists of irregular cavities filled with seminiferous tubules and blood-vessels.
  - **Epididymis**—tortuous tubule, forms long, narrow body which lies along upper and posterior portion of testes.
- **Location**
  - In early fetal life in abdomen below kidneys.
  - Before birth are normally drawn downward to scrotum, and are suspended by spermatic cord.
- **Function**
  - Production of spermatozoa.
  - Production of internal secretion.

Vasa Deferentia or ductus deferentia

- Each duct is a continuation of the epididymis, and is the excretory duct of the testicle. Serves to connect the epididymis and the seminal vesicle of each side.

Seminal Vesicles

- Two sac-like organs located between bladder and rectum on outer side of each vas deferens. Connect vas deferens with ejaculatory ducts.
- **Function**—Serve as reservoirs for semen, to which they add a secretion of their own.

Ejaculatory Ducts
- Formed by union of seminal vesicle and vas deferens of each side.
- They descend, converge, pass between lobes of prostate gland and open into the urethra.

Spermatic Cords
- Each cord consists of a seminal duct, an artery, veins, lymphatics, nerves, and connecting areolar tissue covered with fascia.
- Extend from the internal abdominal ring to the back of the testes.

Scrotum
- Pouch which contains testes and part of each spermatic cord.
- **Structure**
  1. Thin, dark skin, disposed in folds or rugæ, covered with short hairs.
  2. Dartos—consists of elastic tissue, plain muscular tissue and numerous blood-vessels.

Penis
- Organ attached to symphysis pubis and suspended in front of scrotum.
- Consists of three cylindrical bodies of cavernous tissue
  - Two corpora cavernosa penis.
  - One corpus cavernosum urethræ.
- Bound together by fibrous tissue.
- Covered with skin that is continuous with that covering scrotum, perineum and the pubes.
- Urethra—extends from bladder through corpus cavernosum urethræ—7-8 in. long.
- Expansion at lower extremity—glans penis—urethral orifice—covered by foreskin or prepuce.

The Prostate
- Situated in front of the neck of the bladder and around the commencement of urethra.
- **Shape**—resembles chestnut.
- **Consists of** Fibrous capsule containing glandular and muscular tissue. Glandular tissue consists of tubules which empty into urethra.
- **Function**—Secretion of prostatic fluid.

Semen
- Fluid derived from the various sexual glands in the male.
- Spermatozoa are the main elements.

Cowper's Glands
- Located one on each side of prostate gland—about the size of a pea—one inch duct terminates in wall of urethra.
- **Function**—Secretion of a fluid which forms part of seminal fluid.

Female Organs of Generation
- 2 ovaries, which produce the ova and two internal secretions.
- 2 uterine tubes.
- 1 uterus.
- 1 vagina.
- The external genitals.
- 2 breasts.

Ovaries
- Two almond-shaped glandular bodies.
- Situated in posterior fold of broad ligament.
- **Attached**
  - To uterus—by ligament of ovary.
  - To tubes—by fimbriæ.
- **Size**
  - 1½ inches long.
  - ¾ inch wide.
  - ⅓ inch thick.
- **Weight**—2-3.5 gms.
- **Structure**
  - Stroma: Loose meshwork of connective tissue, containing muscle tissue, blood-vessels, lymphatics, and nerves.

Ovaries

- **Structure**
  - Graafian follicles
    1. Outer coat fibrous tissue.
    2. Inner layer of cells contains ovum.
  - Covering of germinal epithelium.
- **Function**
  - Produce, develop, mature, and discharge ova.
  - Form two internal secretions.
  - One secreted by interstitial cells in body of gland—development of secondary sex characteristics dependent on it.
  - One secreted by corpus luteum—function of menstruation dependent upon it.

Uterine or Fallopian Tubes

- **Location**
  - Enclosed in layers of broad ligament.
  - Extend from upper angles of uterus to sides of pelvis.
- **Divisions**
  1. Isthmus—or inner constricted portion near uterus.
  2. Ampulla—dilated portion which curves over ovary.
  3. Infundibulum—trumpet-shaped extremity—fimbriæ.
- **Three Coats**
  1. External, or serous.
  2. Middle, or muscular.
  3. Internal, or mucous, arranged in longitudinal folds and covered with cilia.
- **Function**—Convey ova to uterus.

Uterus

- Hollow, thick-walled organ, placed in pelvis between bladder and rectum.
- **Divisions**
  - Fundus = rounded upper portion, above the entrance of the tubes.
  - Body = portion below fundus, above neck.
  - Cervix = lower and smaller portion which extends into vagina.
- **Three Coats**
  - External, or serous, derived from peritoneum.
  - Muscular
    - Circular layer
    - Longitudinal layer
    - Spiral layer

    Interlaced in every direction.
  - Mucous membrane, lines the uterus.
- **Blood-vessels**
  - Uterine arteries from hypogastrics.
  - Ovarian arteries from aorta.
  - Remarkable for tortuous course and frequent anastomoses.

Uterus

- **Ligaments**
  - Broad, or lateral—two layers of serous membrane.
  - Anterior—peritoneal floor of the utero-vesical pouch.
  - Recto-vaginal—peritoneal floor of the recto-vaginal pouch.
  - Round—two fibromuscular cords.
  - Utero-sacral—two partly serous, partly muscular, ligaments.
- **Function**—To receive ovum, and if it becomes fertilized to retain it until developed and then to expel it.

Vagina

- **Canal**—Extends from uterus to vulva.
- **Three Coats**
  - Outer coat is fibrous and elastic.
  - Middle coat is muscular.
  - Mucous coat, or lining, arranged in rugæ.
- **Location**—Placed between urethra and rectum.

External Genitals

- Mons pubis—a cushion of areolar, fibrous and adipose tissue, in front of pubic bones, covered with skin and after puberty with hair.
- Labia majora—two folds that extend from the mons pubis to within an inch of the anus.
- Labia minora—two folds situated between the labia majora.
- Clitoris—small body, situated at apex of the triangle formed by junction of labia minora. Well supplied with nerves and blood-vessels.
- Hymen—fold of mucous membrane that surrounds vaginal orifice.
- **Glands**
  - Vestibular—oval bodies situated on either side of the vagina.
  - Urethral—glands found chiefly beneath the walls and floor of urethra.

Physiology of Generative Organs

- **Function**
  - Formation and development of ovum.
  - Retention and sustenance of fecundated ovum until able to live outside of body. Expulsion of fetus.
- **Puberty**—Age at which sexual organs become matured and functional. Girl changes to woman.
- **Ovulation**
  - Process of development and maturation of follicle and ovum, and discharge of ovum.
- **Menstruation**
  - A flow of blood from the uterus. Occurs on an average every twenty-eight days. Extends from puberty (14 years) to the menopause, or climacteric (about 45 years). This represents the child-bearing period of a woman's life.
  - Changes in connection with menstrual cycle
    1. General congestion of generative organs, including breasts.
    2. Hypertrophy and congestion of mucous membrane of uterus.
    3. Capillary hemorrhage. Epithelium is cast off.
    4. Following menstruation a new epithelium is formed.
  - **Cause**—Dependent on hormone secreted by corpus luteum.
  - **Purpose**—Nature's way of preparing uterine walls for reception of fertilized ovum.
- **Menopause**—Physiological cessation of the menstrual flow.

Mammary Glands

- **Function**—To secrete milk to nourish infant.
- **Location**
  - Extend from second to sixth rib.
  - Sternum to arm-pit.
- **Structure**
  - Outer surface convex—papilla projects from center called nipple—contains openings of milk ducts. Nipple surrounded by areola.
  1. Consists of connective tissue framework which divides the gland into about twenty lobes.
  2. Lobes are subdivided into lobules.
  3. Lobules are made up of terminal tubules of the duct.
  4. Each lobe possesses its own excretory duct, which is called lactiferous and is sacculated.

Mammary Glands

- **Blood-vessels**
  - Axillary.
  - Internal mammary.
  - Intercostal.
- Nerves—Afferent and vasomotor.
- **Development**
  - Primary development at time of puberty, probably due to internal secretion of ovaries.
  - Functional development follows conception, probably due to hormone produced by mature corpus luteum. Active secretion of milk stimulated by emptying milk ducts.
- **Secretion of milk**
  - Water, Salts, Sugar — Secreted from blood.
  - Proteins, Fat — Formed by disintegration of cells lining lactiferous tubules.

Colostrum—Thin yellowish fluid secreted during first few days of lactation.

Milk

Composition

	Human	*Cow's*
Water	88.4%	88.1%
Proteins	1.5%	3.2%
Fat	3.3%	3.9%
Lactose	6.5%	4.9%
Salts	0.3%	0.9%

Differences

- Different relative proportions.
- **Difference in proteins**
  - Human: Caseinogen 1/3. Lactalbumin 2/3.
  - Cow's: Caseinogen 5/6. Lactalbumin 1/6.
- **Difference in curds**
  - Human—small flocculi.
  - Cow's—heavy curds.
- **Difference in reaction**
  - Human—practically neutral pH 7.0 to 7.2.
  - Cow's—slightly acid pH is 6.6 to 6.8.
- **Bacterial count**
  - Human—sterile.
  - Cow's—sterile, but due to handling it undergoes, it contains large number of bacteria.
- **Germicidal power**
  - Human—Antitoxins and antibacterial substances found in mother's blood.
  - Cow's—May have germicidal value but it is lost by time milk reaches infant.

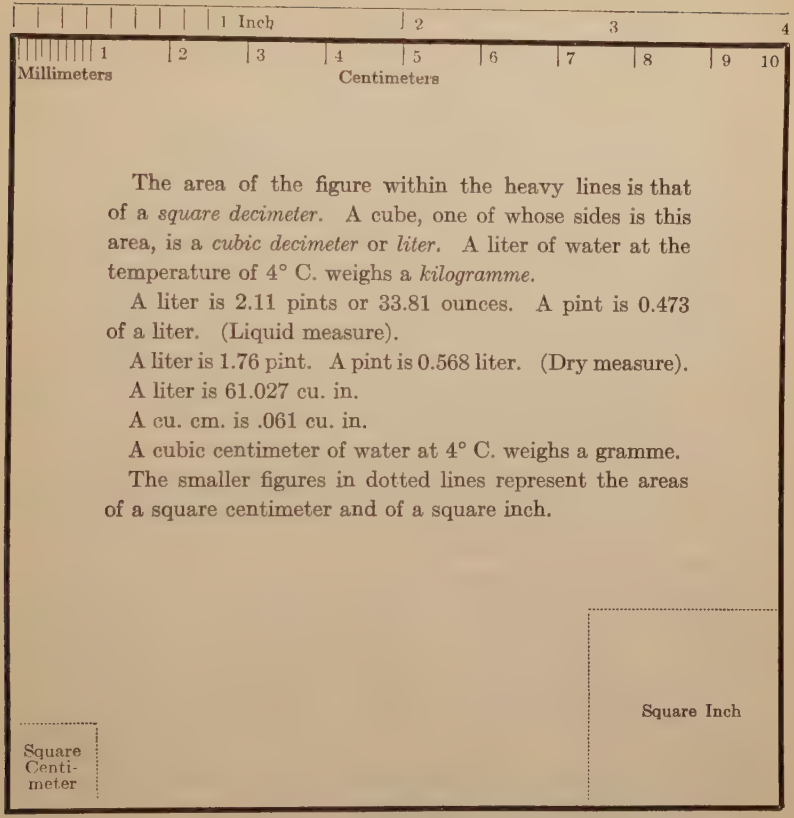
Conception and Pregnancy

- Union of spermatozoon and ovum.
- Occurs in the uterine tubes or near the wall of the ovaries.
- Implies a developing embryo within the uterus.

Segmentation and Intra-uterine Growth

1. Fertilized cell divides into many cells. Collection called blastoderm.
2. Blastoderm composed of: Entoderm. Mesoderm. Ectoderm.
3. Tissues are folded off to from organs.
4. In two weeks' time embryo is ¼ inch long.
5. In four weeks' time embryo is ½ inch long.
6. At four months called a fetus.

Metric System


1 Inch
2
3
4
1
2
3
4
5
6
7
8
9
10
Millimeters
Centimeters
The area of the figure within the heavy lines is that of a square decimeter. A cube, one of whose sides is this area, is a cubic decimeter or liter. A liter of water at the temperature of 4° C. weighs a kilogramme.
A liter is 2.11 pints or 33.81 ounces. A pint is 0.473 of a liter. (Liquid measure).
A liter is 1.76 pint. A pint is 0.568 liter. (Dry measure).
A liter is 61.027 cu. in.
A cu. cm. is .061 cu. in.
A cubic centimeter of water at 4° C. weighs a gramme.
The smaller figures in dotted lines represent the areas of a square centimeter and of a square inch.
Square Inch
Square Centi-meter

1 Meter	= 39.370 inches.	1 Gramme	= 15.432 grains.
1 Decimeter	= 3.937 inches.	1 Decigramme	= 1.543 grains.
1 Centimeter	= .393 inch.	1 Centigramme	= .154 grain.
1 Millimeter	= .039 inch.	1 Milligramme	= .015 grain.
		1 Dekagramme	= 154.323 grains.
		1 Hektogramme	= 1543.235 grains.
		1 Kilogramme	= 15432.350 grains.
		1 Kilogramme	= 35.274 ounces.
		1 Kilogramme	= 2.204 pounds.

Avoirdupois weights are used in weighing the organs of the body. One ounce avoirdupois = 28.35 grammes. For the sake of simplicity in converting figures in the text from one system to the other, we have assumed

1 cm. to equal 2/5 in. (25 mm. = 1 in.).
1 in. to equal 2.5 cm.
1 cc. to equal 15 minims.
30 gm. to equal 1 oz. (dry or liquid measure).
30 cc. to equal 1 oz. (dry or liquid measure).

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THIS GLOSSARY CONTAINS WORDS NOT FULLY DEFINED IN THE TEXT.

Ac'etate. Any salt of acetic acid.

Ac'etone A colorless liquid found in the urine of individuals suffering from defective metabolism, (CH_3COCH_3).

A'cid. An acid substance, containing hydrogen and an acid radical, which dissolved in water or other dissociating liquid produces hydrogen ions. The acid radical must contain a non-metal and may contain oxygen. Examples are hydrochloric acid (HCl), sulphuric acid (H_2SO_4), carbonic acid (H_2CO_3), hydrobromic acid (HBr), nitric acid (HNO_3).

A'cid oxid. An acid oxid (or acid anhydrid) is an oxid of a non-metal which in combination with water will form an acid, as carbon dioxide and sulphur dioxide shown in the following:—

$$CO_2+H_2O \rightarrow H_2CO_3 \text{ (carbonic acid)},$$
$$SO_3+H_2O \rightarrow H_2SO_4 \text{ (sulphuric acid)}.$$

Agglutina'tion. The mutual adhesion or clumping of foreign cells, and loss of motility in the case of motile bacteria, when suspended in fluid containing a suitable agglutinin.

Agglu'tinin. A substance occurring in blood plasma which produces agglutination by its action on the surface of foreign cells.

Ag'gregated. Formed by a collection of several bodies; crowded.

Ag'minated. Arranged in clusters, grouped together, as the agminated glands of Peyer in the small intestine.

Al'anin. Amino-propionic acid $C_2H_4(NH_2)COOH$.

Albu'mins. Thick, viscous substances containing nitrogen, that are soluble in water, dilute acids, dilute salines, and concentrated solutions of magnesium sulphate and sodium chlorid. They are coagulated by heat and strong acids. Examples are: egg albumin and serum albumin of blood.

Al'kalies. The alkalies are the bases of sodium, potassium and ammonium; they give very strong basic action.

Amito'sis. Fission or direct cell-division. Same as akinesis.

Amphib'ia. A class of vertebrate animals that is able to live both on land and in water, as the frog.

Ampul'la. The dilated part of a canal.

Amylop'sin. A pancreatic enzyme which changes starch to maltose. Same as diastase and amylase.

Ana'ërobe. Any microörganism which has the power to live without free air or oxygen.

Anaërob'ic. Thriving best without air.

Anastomo'sis. Communication of branches of vessels with one another.

An'ilin. A colorless oily liquid obtained from coal tar and indigo, $C_6H_5NH_2$.

An'tigens. Immunizing substances which, when introduced into the body of a susceptible animal, produce specific antibodies.

Antineurit'ic. Counteracting neuritis.

Antirachit'ic. Counteracting rickets.

A'pex, pl. Ap'ices. The top or pointed extremity of any conic part.

Arboriza'tion. A branching distribution of veinlets or of nerve filaments, especially the branched terminal ramifications of a nerve axon.

Ar'gon. An element discovered in the atmosphere in 1895. It is the most inert element known.

Arrecto'res pilor'um. The minute involuntary muscles of the skin, whose contraction produces goose-flesh. Also known as arrector and pilomotor muscles.

Asex'ual. Having no distinction of sex; having no relation to sex. Asexual reproduction, reproduction without sexual intercourse.

At'las. The first cervical vertebra by which the head articulates with the spinal column, so called because it supports the head as Atlas was fabled to support the world on his shoulders.

A'tom. An atom is the smallest quantity of an element that can exist and still retain the chemic properties of the element. It is now believed that the atom consists of a central nucleus of positive electrical units (protons) surrounded by negative electrical units (electrons).

Automat'ic. Performed without the will; spontaneous. Same as autonomic.

Autonom'ic. Performed without the will; spontaneous. Same as automatic.

Auton'omy. Independence; the condition of having independent functions, limitations, and laws.

Avi'taminosis. This term signifies the physiological or pathological conditions which arise from deficiency or complete absence of vitamins from the food.

Az'ygos. Without a fellow; bence, unpaired, single.

Base. (1) The lowest part or foundation of anything. (2) The main ingredient of a compound. (3) In chemistry a base is a substance which contains a metal and the hydroxyl (OH) radical. Examples are sodium hydroxide (NaOH) and calcium hydroxide ($Ca(OH)_2$). One exception to this is ammonium hydroxide (NH_4OH), which contains the ammonium radical (NH_4) instead of a metal.

Ba'sic. (1) Pertaining to or having the properties of a base. (2) Capable of neutralizing acids.

Ba'sic oxid. A basic oxid (or basic anhydrid) is an oxid of a metal which in combination with water will give a base, as calcium oxid (CaO) and sodium oxid (Na_2O), shown in the following:—

$$CaO + H_2O \rightarrow Ca(OH)_2 \text{ (calcium hydroxid)},$$
$$Na_2O + H_2O \rightarrow 2\ NaOH \text{ (sodium hydroxid)}.$$

Bas'ilar. Pertaining to a base or basal part.

Ba'sophil. Term applied to leucoytes which stain with basic dyes.

Benzo'ic a'cid. A white crystalline acid $C_7H_6O_2$.

Brachiocephal'ic. Of or pertaining to both the upper arm and head; as the brachiocephalic (innominate) artery and veins.

Bulb. (1) A rounded mass, organ or part. (2) The rounded stem, or leafbud of a plant. (3) The medulla oblongata.

Butyr'ic Acid. A colorless liquid having a strong rancid smell and acrid taste. C_3H_7COOH.

Caffe'in. An alkaloid, $C_8H_{10}N_4O_2$, obtainable from coffee, tea, guana paste, of Brazil, and the kola nut of Central Africa. It is a stimulant to the brain and spinal cord, and to the vasoconstrictor center. It is also a diuretic.

Cal'abar bean. Same as physostigma. The poisonous seed of a climbing plant of Africa.

Cal'cify. Harden by deposit of salts of lime; petrify.

Cal'orie. The Calorie (Cal.) is the amount of heat that is necessary to raise 1000 grams of water through 1° C. Occasionally a small calorie is used. This small calorie is the amount of heat that is necessary to raise one

gram of water through 1° C. It is, therefore, only 1/1000 as large as the Calorie.

Cal'culus, pl. **Cal'culi.** A stone.

Ca'lyx, pl. **Cal'yces.** Small *cup*-like membranous canals, which surround the papillae of the kidney, and open into its pelvis.

Canalic'ulus, pl. **Canalic'uli.** A *small channel*, or vessel.

Ca'nine. Pointed like the tusks of a dog. Name given to the third tooth on each side of the jaw.

Casein'ogen. The curd separated from milk by the addition of rennet, constituting the basis of cheese.

Castra'tion. Removal of the testicles in the male, or the ovaries in the female.

Catab'olism. The process by means of which complex substances are rendered more simple and less complex. The opposite of anabolism.

Catal'ysis. A changing of the speed of a reaction, produced by the presence of a substance which does not itself enter into the reaction.

Cat'alyzer. A substance which acts by catalysis, *i.e.*, modifies the speed of chemical or physical processes. Manganese dioxide is a classical example of a catalyzer. For example, to make potassium chlorate yield up its oxygen it is necessary to raise its temperature to about 360 degrees. If, however, a little manganese dioxide is added, the oxygen is released at a much lower temperature, *viz.* 200 degrees. There are many catalyzers that control chemical reactions in the body.

Ce'cum. (1) Any blind pouch or cul-de-sac. (2) The dilated intestinal pouch into which the ileum, colon, and vermiform appendix open.

Ce'liac. Pertaining to the abdominal *cavity*.

Celluli'tis. Inflammation of cellular tissue. Most common form is inflammation of superficial fascia.

Centrif'ugal. Flying off or proceeding from the center. Same as efferent.

Centrip'etal. Tending or moving toward the center. Same as afferent. Opposed to centrifugal.

Chemo'-recep'tors. Term applied to nerve-endings that are stimulated by suitable concentrations of definite substances.

Chi'asm. A crossing or decussation; especially that of the fibers of the optic nerve.

Chlo'roplast. A plastid containing chlorophyll, developed only in cells exposed to the light. They are minute flattened granules, usually occurring in great numbers in the cytoplasm near the cell wall, and consist of a colorless ground substance saturated with chlorophyll.

Choles'terin. A tasteless, inodorous, fatty substance found in small quantities in the protoplasm of all cells, especially in nerve tissue, blood cells, and bile.

Choles'terol. Same as cholesterin.

Chor'da Tym'pani. The tympanic cord, a branch of the facial, or seventh cranial nerve, which traverses the tympanic cavity and joins the gustatory, or lingual, nerve.

Chro'maffin. Certain cells occurring in the adrenal, cocygeal and carotid glands, along the sympathetic nerves and in various organs, take up and stain strongly with chrome salts, hence called chromaffin. The whole system of such tissue throughout the body is named the chromaffin system.

Chro'maphil. Same as chromaffin.

Cicat'rix The mark, or *scar*, left after the healing of a wound.

Cleavage. The process of division of the fertilized ovum before differentiation into layers occurs. Same as segmentation.

Clon'ic. Pertaining to or of the nature of spasm, in which rigidity and relaxation succeed each other.

Coeffi'cient. In chemistry a number or figure put before a chemic formula to indicate how many times the formula is to be multiplied.

Com'missure. A joining or uniting together. Something which joins together. The angle formed by the junction of the eyelids (same as canthus).

Complemen'tal. Supplying a defect; making complete; accessory.

Com'pounds. (1) Made of two parts or ingredients. (2) Any substance made up of two or more kinds of materials. (3) In chemistry a substance which consists of two or more chemical elements in union.

Con'cept. The image of a thing in the mind.

Cogen'ital. Born with a person, existing from or before birth.

Conjuncti'va. The delicate membrane that lines the eyelids and covers the eyeball.

Conservation. Preservation.

Contig'uous. Adjacent; near, in actual contact.

Convec'tion. A process of transfer or transmission, as of heat or electricity. The term "convection currents" is applied to currents of air produced by differences in temperature and density. Warm air expands, becomes less dense, and is forced upward by the cooler air, which is heavier, and sinks down. In this way convection currents are established.

Cor'onary. A term applied to vessels, ligaments, and nerves which encircle parts like a *crown*, as the coronary arteries of the heart.

Cor'pus Lu'teum, pl. **Corpora Lutea.** Yellow body, in the ovary taking the place of a Graafian follicle which has discharged its ovum.

Correla'tion. The interdependence of organs or functions; the reciprocal relations of organs.

Crena'ted. *Notched* on the edge.

Crib'riform. Perforated *like a sieve.*

Cru'ra Cer'ebri. Pillars of the *cerebrum.*

Cyano'sis. Blueness of the skin, resulting from insufficient oxygenation of the blood.

Cysti'tis. Inflammation of the bladder.

Decomposi'tion. (1) The separation of compound bodies into their constituent parts or principles. (2) Any ordinary process of decay, especially putrefaction.

Decussa'tion. To cross in the form of the letter X.

Dehydra'tion. Removal of water from a substance or compound.

Delir'ium cor'dis. Violent, tremulous beating of the heart.

Del'toid. Having a triangular shape; resembling the Greek letter △ (*delta*).

Dial'ysis. The passage through a permeable membrane of a substance in solution.

Diapede'sis. *Passing* of the red blood cells *through* vessel walls without rupture.

Diath'esis. A congenital condition of the system which renders it peculiarly liable to some diseases.

Dichot'omous. Divided into two. Pertaining to or consisting of a pair or pairs.

Diges'tion. (1) The process of converting food into substances that can be absorbed and assimilated. (2) The subjection of a body to prolonged heat and moisture, so as to disintegrate and soften it.

Disc. (1) A circular or rounded flat plate or organ. (2) A medicated lamella.

Dis'cus Prolig'erus or **germ disc.** A term applied to a mass of cells clinging to the ovum when it is set free from the ovary. More recent term is "ovarian mound."

Distilla'tion. The act of distilling or of falling in drops. The operation of driving off gas or vapor from volatile liquids or solids, by heat in a

retort or still, and the condensation of the products as far as possible by a cooler receiver.

Diure'sis. Increased secretion of urine.

Ectop'ic. Characterized as being *out of place.*

Ectop'ic Gesta'tion. The name given to pregnancy, when the fecundated ovum, instead of entering the uterus, remains either in a Fallopian tube or the abdominal cavity.

Ede'ma. A *swelling* from effusion of serous fluid into the areolar tissue.

Effec'tor. A nerve end-organ which serves to distribute impulses which activate muscle contraction and gland secretion.

El'ements. (1) Any one of the primary parts or constituents of a thing. (2) In chemistry a substance which cannot be separated into more simple substances by chemical means.

Electrons. Negative electrical units which with positive electrical units constitute atoms.

Em'bolus. A portion of a blood clot which has been formed in one of the larger vessels, and has afterward been forced into one of the smaller vessels, where it may act as a wedge.

Em'bryo. The ovum and product of conception up to the third month, when it becomes known as the fetus.

Empir'ical. Relating to a knowledge of medicine obtained by experience alone.

Emul'sion. A mixture of two immiscible fluids, where one is scattered through the other in the form of finely divided globules.

Endemic. Occurring frequently in a certain district.

En'docrin. Pertaining to internal secretions.

Endog'enous. Originating within the organism; not exogenous.

En'ergy. Ability to operate or work; power to produce motion, to overcome resistance, and to effect physical changes.

Equilib'rium. That condition of rest which results when all the forces acting in a body are equally opposed. In physiology it signifies the harmonious action of the organs of the body, as in standing.

Evagina'tion. A protrusion of some part or organ.

Evapora'tion. The act of resolving into vapor. In order to produce vapor, heat is necessary and, if not supplied, is taken from near objects. Thus the heat necessary for the evaporation of perspiration is taken from the body.

Exog'enous. Developed outside the body.

Exophthal'mic. Pertaining to or characterized by abnormal protrusion of the eyeball.

Extero-receptors. Term applied to the endings of sensory nerves located at the surface of the body, which are stimulated by influences outside the body, *e.g.*, pain spots, heat spots, cold spots, etc.

Fal'ciform. Sickle-shaped.

Fascic'ulus, pl. **Fascic'uli.** A bundle of close-set fibers.

Fecunda'tion. The act of making fruitful or prolific. Impregnation.

Fe'tus. The child in the womb from the third month of pregnancy till birth.

Fibril'la, pl. **Fibril'læ.** A *little fiber,* or filament.

Fibrilla'tion. (1) The quality of being fibrillæ. (2) Muscular tremor. (3) A condition of muscular action, particularly of the heart muscle, in which the individual fibers take up their own independent action, producing an incoördinate contraction.

Fim'bria, pl. **Fim'briæ.** A border or *fringe.*

Flat'ulence. Undue generation of gases in the stomach and intestines.

Funic'ulus, pl. **Funic'uli.** (1) The umbilical cord. (2) The spermatic cord (3) One of the bundles of nerve fibers of which a nerve trunk is made up.

Gan'glion, pl. **Gan'glia.** A collection of nerve cells in the course of a nerve, having the appearance of a knot.

Gastrula'tion. The formation of a two layered embryo (gastrula) from the blastula.

Gen'erative. Pertaining to generation, or propagation. Connected with or resulting from the process of begetting.

Gen'ito-u'rinary. Relating to the genital and urinary organs.

Gesta'tion. The act or condition of carrying young in the womb from conception to delivery. Pregnancy.

Gli'a. The neuroglia.

Glob'ulins. Protein substances somewhat similar to the albumins, but differing in their solubility.

Glomer'ulus. A botanical term signifying a small, dense, roundish cluster: a term applied to the ball-like tuft of vessels in the cortical portion of the kidneys.

Glu'cose. Grape-sugar or dextrose, $C_6H_{12}O_6$. Found in honey, fruit, etc.; also blood, lymph, and diabetic urine.

Glute'i, pl. of **Glute'us.** The muscles forming the *buttocks.*

Gly'cocoll. (1) Gelatin-sugar or amino-acetic acid (CH_2NH_2COOH). (2) Any substance of the group to which glycocoll belongs.

Gly'cogen. A form of animal starch, $(C_6H_{10}O_5)$. Found in the liver, muscles and other tissues.

Glycogen'esis. The production of sugar or glycogen.

Glycogenol'ysis. Conversion of glycogen into glucose.

Glycosu'ria. The presence of sugar in the urine.

Go'nads. Term applied to the ovaries of the female, and the testes of the male.

Graaf'ian Fol'licles, or Ves'icles. A term applied to the sacs in the ovaries, which contain the ova, or cells.

Granula'tions. Grainlike, fleshy bodies that form on the surface of wounds and ulcers.

Heart block. The condition in which the connection between the auricles and ventricles by means of the bundle of His is interrupted, so that the auricles and ventricles beat independently of each other.

Hem'atin. A protein-free, pigmented constituent of hemoglobin obtained by treating with acids.

Hemoglo'bin. A compound protein found in the red cells of the blood; its molecule consists of a protein portion and of a pigment portion, the latter containing one atom of iron.

Hemophil'ia. A congenital, morbid condition, characterized by a tendency to bleed immoderately from any insignificant wound, or even spontaneously.

Hemorrhoi'dal. Pertaining to hemorrhoids, small tumors of the rectum, which frequently *bleed.*

Hi'lum, sometimes written **Hi'lus.** It is the depression, usually on the concave side of a gland, where vessels, and ducts enter or leave.

Homoge'neous. Of the *same kind* or quality throughout; uniform in nature; the reverse of heterogeneous.

Horizon'tal. Of, at, the horizon; parallel to the plane of the horizon, at right angles to the vertical.

Hyperglyce'mia. An abnormal amount of sugar in the blood.

Hyperthy'roidism. A condition due to excessive functional activity of the thyroid.
Hyperton'ic. Showing abnormally great tension.
Hypoth'esis. Supposition made as basis for reasoning, without reference to its truth, or as starting point for investigation; groundless assumption.
Hypoton'ic. Marked by abnormally low tension.

Il'eum. The *twisted* portion of the small intestine.
Il'ium, pl. **Il'ia.** The upper part of the os innominatum.
Immis'cible. Not capable of being mixed.
In'dican. (1) A yellow glucosid obtained from indigo. (2) A principle found in sweat and urine. It is derived from the indol formed (a) in the intestines during putrefaction, and (b) from putrefaction of body tissues as in abscess formation.
In'dol. A crystallizable body, C_8H_7N, from indigo, feces, etc.; one of the products of intestinal indigestion.
In'guinal. Pertaining to the groin.
Inocula'tion. The injection of virus into any part of the body, either as an operative procedure or by accident.
Inoscu'late. To unite, to open into each other.
In'sulate. To isolate or separate from surroundings.
In'sulin. Name given to hormone of the internal secretion of the pancreas.
Intero-receptors. Term applied to nerve-endings located in the digestive system, which are stimulated by conditions in this system, *e.g.*, taste receptors, receptors in stomach, etc.
Intersti'tial. Pertaining to or containing *interstices.*
Invag'inate. To thrust one portion within another portion of the same thing.
Is'chium, pl. **Is'chia.** The lower portion of the os innominatum; that upon which the body is *supported* in a sitting posture.
Isoton'ic. Having a uniform tonicity or tension.

Kryp'ton. A gas found in the atmosphere.

Lacta'tion. The period of giving *milk.*
Lacu'na, pl. **Lacu'næ.** A little *hollow space.*
Lambdoi'dal. Resembling the Greek letter Λ.
Lamel'la, pl. **Lamel'læ.** A thin plate, or layer.
Lam'ina. A thin plate; a germinal layer.
Laryn'goscope. The instrument by which the larynx may be examined in the living subject.
Lens. A transparent substance, usually glass, bounded by two curved surfaces, or by one curved and one plane. There are two general classes of lenses: (1) concave, which are thinner at the center than at the edges; and (2) convex, which are thicker at the center than at the edges. (See page 488.)
Lig'ature. (1) A thread or wire for tying a vessel. (2) The act of applying a ligature.
Ly'sin. An antibody which has the power to dissolve bacteria.

Macera'tion. The softening of a solid by soaking.
Malle'olus, pl. **Malle'oli.** A name given to the pointed projections formed by the bones of the leg at the ankle joint.
Manom'eter. An instrument for measuring the pressure or tension of liquids or gases.
Maras'mus. Progressive wasting and emaciation, especially in young infants.
Matura'tion. The process of bringing or of coming to maturity. In physi-

ology the term is applied to the reduction of the chromosomes that takes place before the fusion of the sperm and egg nuclei.

Mechanico-receptors. Term applied to nerve-endings that are stimulated by mechanical means, *i.e.*, pressure, vibratory impacts, etc.

Mesoco'lon. A duplicature of the peritoneum covering the colon.

Mi'cron. One thousandth of a millimeter (0.001 mm.).

Mito'sis. Processes of indirect cell division. Same as karyokinesis.

Mix'tures. (1) In medicine, a preparation of various ingredients. (2) From a chemical standpoint a mixture can be made up of either or both elements and compounds. These can often be separated by simple physical means, as filtration or evaporation.

Mononu'clear. Having but one nucleus.

Mo'tor. (1) Producing or subserving motion. (2) A muscle, nerve or center that affects or produces movement.

Mu'cin. The chief constituent of mucus.

Myogen'ic. Originating in muscular tissue.

Myoneu'ral. Pertaining to both muscle and nerve.

My'osin. Chief protein substance of muscle.

Na'ris, pl. **Na'res.** A nostril.

Neurasthen'ic. The name for a group of symptoms resulting from some functional disorder of the nervous system, with severe depression of the vital forces. It is usually due to prolonged and excessive expenditure of energy, and is marked by tendency to fatigue, lack of energy, pain in the back, loss of memory, insomnia, constipation, loss of appetite, etc.

Neurogen'ic. Originating in nerve tissue.

Nic'otin. An acid, colorless, fluid base obtained from tobacco; exceedingly poisonous.

Nucle'olus, pl. **Nucle'oli.** A smaller nucleus within the nucleus.

Nleu'cus, pl. **Nu'clei.** A minute vesicle embedded on the cell protoplasm.

Odon'toid. Tooth-like.

Ol'igu'ria. Deficient secretion of the urine; abnormally diminished frequency of micturition.

Op'timal. Most suitable or favoring.

Organ'ic. (1) Pertaining to an organ or organs. (2) Having an organized structure. (3) Arising from an organism. (4) In chemistry, a compound containing carbon.

Os, pl. **O'ra.** A mouth.

Os, pl. **Os'sa.** A bone.

Os Cox'æ, pl. **Os'sa Cox'æ.** The hip bone, or os innominatum.

Osmo'sis. The passage of fluids and solutions, separated by a membrane, or other porous septum, through the partition, so as to become mixed or diffused through each other.

Os'sa Innomina'ta, pl. of **Os Innomina'tum.** "Unnamed bones." The irregular *bones* of the pelvis, *unnamed* on account of their non-resemblance to any known object.

Os'teoblasts. The *germinal* cells deposited in the development of *bone.*

O'toliths. *Particles* of calcium carbonate and phosphate found in the internal *ear.*

O'vum, pl. **O'va.** The female germ cell.

Oxida'tion. As usually used, the union of oxygen with metals and non-metals, more technically oxidation is removing electrons.

Papil'læ, pl. of **Papil'la.** Minute eminences on various surfaces of the body.

Parturi'tion. The act of giving birth to young.

Ped'icle. A stalk.
Pedun'cle. A narrow part acting as a support.
Perikar'yon. The cell body as distinguished from the nucleus and processes.
Perpendic'ular. At right angles to the plane of the horizon; erect, upright, in standing position.
Phimo'sis. Tightness of the foreskin, so that it cannot be drawn back from over the glans; also the analogous condition in the clitoris.
Phlebot'omy. The opening of a vein; venesection.
Phona'tion. Utterance of vocal sounds.
Phos'phate. Any salt of phosphoric acid.
Phren'ic. Pertaining to the *diaphragm.*
Phys'ical. Pertaining to nature, or to the body.
Phys'ics. The science of the laws and phenomena of nature, but especially of the forces and general properties of matter.
Po'lar. Of or pertaining to a pole.
Polar'ity. Tendency of a body to place its mathematical axis in particular direction.
Potential'ity. State or quality of being possible.
Precip'itins. Antibodies which are capable of producing precipitation of bacteria.
Prona'tion. The turning of the hand with the palm downward.
Prona'tor. The group of muscles which turn the hand palm downward.
Pro'prio-receptors. Term applied to nerve-endings located in deeper regions of the body, stimulated directly by processes within the body, and indirectly by environmental forces, *e.g.*, pressure receptors of muscles, tendons, ligaments, etc.
Prosecre'tin. The precursor of secretin, thought to be contained in epithelial cells of the duodenum, and to be converted into secretin on hydrolysis with acids.
Pseudopo'dium. A protrusion of the substance of an ameba or an ameboid cell, as in locomotion.
Psy'chical. Pertaining to the mind.
Pu'berty. Sexual maturity in the human race; the age at which reproduction becomes possible.
Pu'bis, pl. **pu'bes.** The hairy region above the genitals, also used for os pubis, the portion of the os innominatum forming the front of the pelvis.
Pyogen'ic. Producing pus.
Pyrex'ia. Elevation of temperature; fever.

Quadrigem'inal. Fourfold, or in four parts.
Quies'cent. Motionless, inert, silent, dormant.

Radia'tion. The act of spreading outward from a central point. The diffusion of rays of light.
Ra'dio-recep'tors. Term applied to nerve-endings which are stimulated by the effects of radiant energy, *e.g.*, heat receptors, cold receptors, etc.
Râle. A rattling, bubbling sound attending the circulation of air in the lungs. Different from the murmur produced in health.
Rec'tus, pl. **Rec'ti.** Straight. A name given to muscles of the eye and abdomen.
Reduc'tion. As usually used, means removing oxygen, more technically, reduction is adding electrons.
Reflec'tion. The return of rays, beams, sound, or the like from a surface. Reflection of light is of two kinds, *regular* and *diffused.* When a beam of light enters a darkened room through a small opening and strikes a mirror, a reflected beam will be seen traveling along some definite

path. This is called *regular reflection.* Should the light, however, fall on a piece of white paper, it would be reflected and scattered in all directions. This is called *diffused reflection,* and is caused by the inequalities of the reflecting surface. All rough surfaces, as well as dust and moisture in the atmosphere, serve to diffuse light. If this were not the case, it would be dark everywhere except in the direct path of light from some luminous body.

Refrac'tion. The bending or deviation in the course of rays of light in passing obliquely from one transparent medium into another of different density.

Regurgita'tion. (1) The casting up of undigested food. (2) A backward flowing of the blood through the left auriculoventricular opening on account of impefect closure of the mitral valve.

Resil'iency. The act of leaping, or springing back; the act of rebounding.

Retic'ular. Resembling a *small net.*

Retrogress'ion. (1) Degeneration. (2) Catabolism.

Ru'gae, pl. **of Ruga.** A term applied to the folds, or *wrinkles,* in the mucous membrane, especially of the stomach and vagina.

Saliva'tion. An excessive secretion of saliva.

Salt. (1) Sodium chlorid. (2) Chemically a salt is a substance containing the metal from a base and the acid radical from an acid. Salts may be obtained by the neutralization of an acid by a base, the characteristic hydrogen of the acid combining with the characteristic hydroxyl of the base to form water, leaving the salt as shown in the following:—

Base + Acid → Water + Salt

$NaOH + HCl \rightarrow H_2O + NaCl$ (sodium chlorid),

$Ca(OH)_2 + H_2SO_4 \rightarrow 2H_2O + CaSO_4$ (Calcium sulphate).

Saponifica'tion. Conversion into soap.

Sciat'ic. Pertaining to the ischium.

Secre'tagogue. An agent which stimulates secretion.

Segmenta'tion. The process of division of the fertilized ovum before differentiation into layers occurs. The same as cleavage.

Ses'amoid. *Resembling a grain of sesamum.* A term applied to the small bones situated in the substance of tendons, near certain joints.

Si'nus. (1) A recess, cavity or hollow space. (2) A dilated channel for venous blood; found chiefly in the cranium. (3) An air cavity in one of the cranial bones, especially the ethmoid, frontal, maxilla, and sphenoid sinuses.

Ska'tol. A strong-smelling crystalline substance from human feces. It is produced by the decomposition of proteins in the intestines.

Solute'. A substance dissolved in a solution.

Sol'vent. (1) Dissolving; effecting a solution. (2) A liquid that dissolves or is capable of dissolving.

Somat'ic. Pertaining to the body.

Speci'fic grav'ity. By specific gravity is meant the comparison between the weight of a substance and the weight of an equal volume of some other substance taken as a standard. The standards usually referred to are air for gases, and water for liquids and solids. For instance, the specific gravity (sp. gr.) of carbon dioxide (air standard) is 1.5, meaning that it is 1.5 times as heavy as an equal volume of air. Again the specific gravity of mercury (water standard) is 13.6 meaning that mercury is 13.6 times as heavy as an equal volume of water. The specific gravity of solutions, as a salt solution, will necessarily vary with the concentration.

Sper'matocyte. The mother cell of a spermatozoön.

Sphinc'ter. A circular muscle which contracts the aperture to which it is attached.
Splanch'nic. Of or pertaining to the viscera.
Stimu'lus, pl. **Stim'uli.** Anything that excites to action.
Sto'ma, pl. **Sto'mata.** A *mouth*; a small opening.
Sul'phates. Any salt of sulphuric acid.
Summa'tion. Addition, finding of total or sum.
Su'ture. That which is *sewn together*, a seam; the seam uniting bones of the skull.
Syn'apse. Interlacing of terminal arborization of nerves.

Ten'do Achil'lis. "Tendon of Achilles." The *tendon* attached to the heel, so named because *Achilles* is supposed to have been held by the heel when his mother dipped him in the river Styx to render him invulnerable.
Tet'any. A disease characterized by painful tonic and symmetric spasm of the muscles of the extremities.
Thermogen'esis. The production of heat, especially the process of generating heat within the animal body.
Thermol'ysis. (1) Dissociation by means of heat. (2) The dissipation of bodily heat.
Thermotax'is. (1) The normal adjustment of the bodily temperature. (2) The movement of organisms in response to heat.
Throm'bus. Name given to a clot formed in a blood-vessel.
Thyrox'in. A crystalline compound $C_{11}H_{10}O_3NI_3$, isolated from the thyroid gland, and having the properties of thyroid extract.
Tone. (1) The normal degree of vigor or tension; a healthy state of a part.
Trabec'ulæ. A term applied to prolongations of fibrous membranes which form septa, or partitions.
Trape'zius. A name given to the two upper superficial muscles of the back, because together they resemble a *trapezium*, or diamond-shaped quadrangle.

Unicel'lular. Composed of a single cell.

Vac'uoles. Any space or cavity formed in the protoplasm of a cell.
Vac'uum. A space from which the air has been exhausted.
Ver'miform. Worm-shaped.
Ver'nix Caseo'sa. The *fatty varnish* found on the new-born infant, which is secreted by the sebaceous glands of the skin.
Ver'tebra, pl. **Ver'tebræ.** The bones of the spine.
Vis'cid. Clammy; glutinous or sticky.
Viscos'ity. The quality of being viscous.
Vis'cous. Sticky or gummy; viscid.
Vit'iated. Impairment of quality; debased, corrupted.

Xerophthal'mia. Conjunctivitis with atrophy and no liquid discharge, producing a dry and lustreless condition of the eyeball.

Zy'mogen. A mother substance or antecedent of an enzyme.

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